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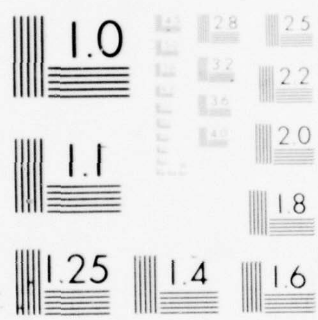

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REPORT NO. CG-D-128-76

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RECREATIONAL BOAT SAFETY COLLISION RESEARCH-PHASE II

VOLUME I - PROBLEMS DEFINITION; SAFETY ENHANCEMENT CONCEPTS

13

JULY 1976

FINAL REPORT

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U.S. DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD
OFFICE OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C. 20590

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16. Abstract

The conditions surrounding recreational boating collisions were probed in an attempt to obtain the information required to document probable causes and possible collision reduction techniques.

This document summarizes the results of research accomplished to date as well as required additional efforts, with regard to the following:

1. Results of three experiments designed to measure the effects of certain stressors on the performance of pleasure boat operators;
2. Results of a data analysis effort designed to identify the presence of stressors in pleasure boat collisions;
3. Collision cause problem identification using inputs from experiments, data analysis, and Collision Research, Phase I, results; and
4. Collision reduction method identification (Safety Enhancement Concepts).
5. Problems requiring further research.

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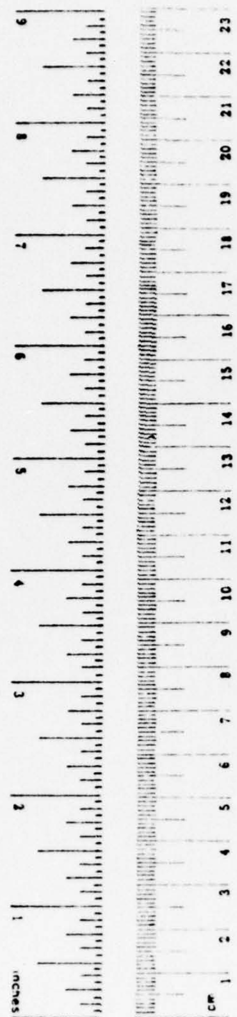
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

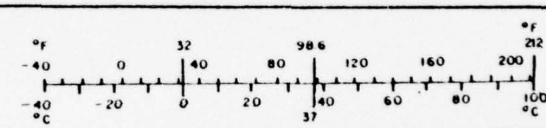
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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VOLUME I

PROBLEMS DEFINITION; SAFETY ENHANCEMENT CONCEPTS

1.0 INTRODUCTION

In 1974 research was initiated into the pleasure boat collision problem. The main effort involved cause identification. Coast Guard collision accident statistics were studied, probable causes were identified, and initial results showed that 90% of the causes were operator error-related. The hypothesis was made that the operator fails because of the interaction of many stressors and with the exception of isolated instances the elimination or reduction of these stressors will have a beneficial effect on his level of fatigue and, hence, his chances of detecting a dangerous situation and avoiding a collision.

An experiment was designed to measure the performance of boat operators to a visual task while they were operating a boat under "normal" conditions of heat, sun, glare, noise, shock/vibration, fatigue, and alcohol (stressors). The apparatus was designed, built, and tested in a two day experiment at the conclusion of the Phase I effort. The experiment, designed to measure the cumulative effects of fatigue, showed significant fatigue effects both in reaction times and missed signals.

The results of the first Visual Alertness Stressor Test (VAST) along with the results of the equipment-oriented survey conducted as part of Phase I (Reference 1) provided the basic guidelines for the Phase II research effort which was comprised of:

- a VAST experiment designed to determine the effects of alcohol on boat operator performance (Section 2.0),
- a VAST experiment designed to determine the combined and individual effects of fatigue, alcohol, noise, shock, and glare on operator performance (Section 2.0),

- a complex data analysis effort designed to identify causes of collisions with emphasis on determining if it is possible to detect the presence of certain stressors and human engineering problems in current collision data (Section 3.0),
- the identification of boat design parameters that impair operator performance and may contribute to the cause of collisions (Section 4.0),
- the identification of problems involved in collisions that if eliminated or reduced would reduce the collision rate (Section 5.0),
- the determination of solutions to those problems called safety enhancement concepts, along with effectiveness estimates of those concepts (Section 5.0),
- the identification of problems that require more research to find solutions (Section 6.0).

The Coast Guard also initiated a program of in-depth collision accident investigations, wherein trained investigators from Wyle Laboratories were sent to investigate collisions as soon as possible after they occurred. By talking with the victims and witnesses, by examining the boat(s), and by studying the collision area, the investigators were able to recreate the circumstances leading up to the collision and the collision itself in greater detail than would have been possible if: 1) the collision had been investigated some time after the occurrence, or 2) the details of the collision had been gleaned from BARs. In addition, Wyle could investigate collisions that MIOs are not able to investigate; i.e., those which occurred in state jurisdiction waters and non-fatal collisions (Reference 2). (See Volume II, this report.)

The Phase II collision research report has been divided into two volumes for convenience. A summary of Volume I was presented above. Volume II summarizes the information obtained from the 1975 collision accident investigation program. Statistics from all reported collisions are examined and details from the ten collisions that were investigated are discussed.

2.0 BOAT OPERATOR PERFORMANCE EXPERIMENTS

2.1 Introduction

The Coast Guard has been studying boating accident causes for several years, and has financed numerous studies by various outside organizations to study causes. In every case, from small studies of a particular type of accident to large scale studies of accidents in general (CG-357), the estimates of the total number of accidents caused by the operator or operator-related problems was over 50 % . In collisions, these estimates ranged from 65 to 90 %.

These cases were generally attributed to inexperience, lack of education in boating safety, poor operator attitudes or motivation (inattentiveness, carelessness), or recklessness. In many cases, however, it was felt that environmental stressors were either the primary cause or a significant contributory cause.

The Visual Alertness Stressor Test (VAST) experiments and research program grew out of the Coast Guard's need to know about operator stressors and their effects on performance and the probability of an operator error. The concept of stressor-induced accidents is not new, nor is it peculiar to boating. Succeeding subsections will outline the stressor problem in boating (Section 2.2) and research in other fields which might be applicable (Section 2.3). The result of the problem definition and literature search was the design of the VAST apparatus and experimental concept (see Section 2.4).

Three VAST experiments have been designed and completed to date. The first dealt with combined stressors under the label of "fatigue" (see Section 2.5). The second study involved fatigue and alcohol (see Section 2.6). Finally, in December of 1975, a large-scale VAST experiment was implemented including research on five major stressors (alcohol, fatigue, glare, noise, and shock/vibration) and their interactions. The third VAST experiment is discussed in detail in Section 2.7. Discussions of the information that has been gathered so far and its meaning are included in Section 2.8. Finally, a glossary of statistical and psychological terms and concepts that are used is included, along with Appendix D concerning the error measure d'. The reader who has trouble with these terms and concepts should consult these sections.

The VAST program has made dramatic and significant progress in the analysis of stressors and stressor effects in boating. The research has been real-world oriented and straightforward in the breakdown of the boating environment into component stressors. Of course, as with most worthwhile research endeavors, many questions have been raised as well as answered. The problems of glare and heat stress have not been adequately treated as yet. Nighttime collisions account for a large percentage of all collisions, and yet, VAST has not been applied to the various additional stressor problems after dark (night vision, confusing lights on the horizon, glare from some navigation light configurations, etc.). In a sense, VAST has opened Pandora's box. We have found a new measuring tool, and now the entire realm of stressors and stressor effects awaits us. Guidance from other recently-developed tools (such as the Accident Recovery Model) and accident investigations will prove invaluable in ordering the priorities for future applications of VAST.

2.2 Problem Definition

As was mentioned in the introduction, past investigations have shown that up to 90% of the causes of boating accidents are people-related. The USCG summary statistics for 1974 (CG-357, 1974) show that people-related causes account for 65% of the reasons for fatal accidents. The 1974 collision accident investigations (Reference 2) done at Wyle show this fraction to be 90.5%, and the Wyle interview of nighttime collision victims (see Reference 3) generated a figure of 89.2%. Thus, a large percentage of boating accidents are caused by operators or operator-related factors.

What causes operator errors? Is it lack of education or inexperience? Is it one of those poorly defined words such as carelessness, inattention, or negligence? Or is the cause the presence of external influences which have become known as stressors? In truth, "the cause" is probably a combination of these things, and other causes (such as human factors or boat design).

Obviously, there are stressors in boating. The boat operator is much more exposed than an automobile driver, for example. Most boat drivers have no air conditioner to counteract heat; some have no muffler, fire wall, roof, or radio to overcome engine noise, no roof to help with wind, glare, and sun, no seat designed to counteract shock and vibration, no sophisticated

cockpit design to aid in visibility and operation, and no injury prevention or crashproof design to the cockpit surroundings. Alcohol effects both the car and boat operator, but there is greater potential for the detrimental effects of alcohol to be increased by combining with other stressors in boating.

Given the presence of stressors in boating, the issue becomes, do they have any effect on performance, and if so, how do we find out? This is the problem that the VAST research effort addresses.

What are stressors, and what does "stress" mean? In terms of human performance, stress is not something the individual defines, but is a characteristic or set of specifications of the demands placed upon the individual by himself, the task, and the environment. This definition of stress makes it manipulable (an independent variable) and frees the definition from subjective impressions of what is stressful or what is challenging. It is clear from this definition that not all stress leads to performance decrements. Indeed, boredom may be defined as the result of a stressless situation. Thus, optimal performance may be obtained at some intermediate level of stress (church pews may be hard - stressful - merely to keep one awake and attentive). In the boating accident situation, one is concerned with several aspects of stress: principally task overload (too many boats or too tough boating conditions to operate safely) and environmental stress (noise, glare, etc.). However, might we have situations of too little stress (as defined above) leading to boredom and inattentiveness? Our present concern is with environmental stress (and task overload to an extent). The critical issues are: <u>do</u> stressors cause accidents, <u>what</u> stressors are of concern and <u>how</u> do the stressors act to affect boater performance?

Environmental stress can come from various sources and, obviously, higher levels of stress lead to poorer performance. However, we should realize how adaptable man is to stress. The eye and the ear can tolerate changes in intensity and frequency that demand logarithmic scales because of their magnitude, without severely changing man's performance. Man is affected by heat, vibration, glare, etc., but not nearly so easily as computers and other devices of similar complexity. The astounding tolerance of man makes it even more critical that we discover where his limits are. As research continues we find these limits of performance are often reached before subjective feelings of discomfort are encountered. These are probably the areas of the most difficulty with respect to safety because the individual does not realize he has been influenced, and may not realize it even after an accident.

Stressor research from other areas will be outlined in Section 2.3, but several points can be raised that illustrate the nature of the problem. Different sources of stress are typically not additive in their effects but interactive. This demands that one investigate all stressors in a situation for their individual and interactive effects. For example, studies on information processing have shown that loss of sleep leads to poorer performance and high levels of environmental noise lead to poorer performance. However, when the two stressors were combined, the noise increased the level of arousal, compensating for the lack of sleep, and performance was better than under either stressor alone. The point? Stress should not be considered as a single thing, and stressor interactions should be studied as well as individual stressors.

Stress, then, is not a simple idea, but a complex one. The effects of stress are not static, but dynamic, i.e., they change as the task goes on. One formulation of this idea is the Yerkes-Dodson Law, which claims that the optimal level of irrelevant stimulation increases as the level of task difficulty decreases. This suggests, for example, that as one learns a task, he can tolerate more and more stress while maintaining the same level of performance. In fact, more stress may be desirable to avoid boredom after learning. How might the Yerkes-Dodson Law apply to fatigue? It would predict that one could tolerate less stress under fatigue than otherwise. Thus, a certain amount of glare may not be a factor when heading out to fish, but a lesser amount of glare, after you've been fishing all day and are fatigued, may be a significant factor. Individual differences are important in stressor effects as well. Of critical importance then, is the complex nature of stress and stressor effects, and the ability of the individual to maintain his attention upon relevant information in the performance of his tasks (see Figure 2-1).

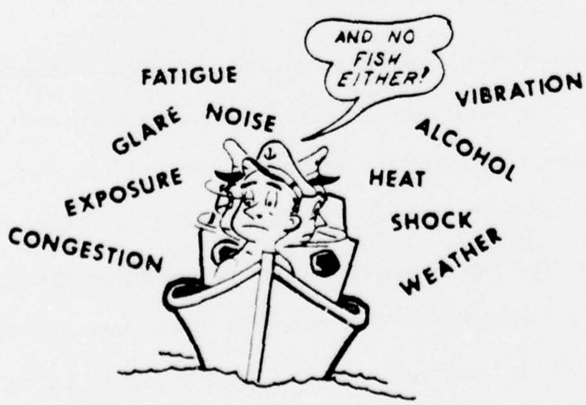

FIGURE 2-1. OPERATOR STRESSORS

The problem that the VAST program was to address was the effects of stressors in boating. The overall pattern of research that is presented in this report reflects the logical progression of the program: 1) review the relevant findings from other sources, 2) determine if the "worst case" (all stressors combined) leads to a performance degradation — this was the VAST-1 experiment (see Section 2.5), and 3) if the "worst case" does lead to a performance degradation (which it did), then begin to analyze the individual stressors — this was done in VAST-2 and VAST-3 (see Sections 2.6 and 2.7).

2.3 Background Literature

The idea of looking at stressors as potential accident causes is not new. In automobiles, aircraft, and industrial environments, stressors such as heat, glare, noise, vibration, weather, control forces, and alcohol have been found to be significant. This research forms a basis for investigating stressors in boating. Several questions then arise. Are stressor effects similar in boating to those in cars and planes? Are there new and different stressors in boating? What is the best way to approach these problems in researching the area? What has worked in the past? The following paragraphs will outline the previous research in specific stressor areas and the implications for research in boating.

Without an adequate level of contrast, one cannot see anything. If the brightness of a boat and its background are very similar, for example, then that boat may be very difficult to see. Low contrast can be caused by haziness, clouds, glare and general brightness, dark adaptation, and certain color combinations (such as a pale blue boat against a blue sea and sky). A.D. and P. Louie (Reference 4) found that detection times for visual targets increased as the contrast associated with the target decreased. A.M. Mayyosi, et al. (Reference 5), have shown a decrease in dynamic visual acuity (the ability to discriminate and identify objects which are moving relative to the observer) under low contrast conditions.

Glare is a major stressor in vision, and can cause low contrast conditions. There are numerous sources of glare in boating: sun, water, windshields, windshield frames, guard rails, chrome trim, decks, horns, instruments, and other shiny surfaces. Glare may cause a reduction in brightness differences by making everything bright (leading to low contrast). Even after a

glare source is removed, after-effects may persist. Glare after-effects typically are the creation of "dark spots" in the visual field which may persist for several minutes, depending upon the length of exposure. Glare sources may be terminated by clouds or pulling into a shaded channel. In these cases, the operator's vision will be impaired until his eyes adjust to the reduced overall lighting. Glare has received considerable attention in research in the past ten years, from Schmidt's work (Reference 6) to Hicks (Reference 7) and other recent efforts.

Mortimer and Jorgeson (Reference 8) and Begbie (Reference 9), among others, have found alcohol to cause reductions in the visual field (peripheral vision) and delays in eye fixation times (the time required to move the eyes to a new line of sight). Moskowitz and Sharma (Reference 10) found evidence that alcohol interferes with central information processing rather than peripheral sensory mechanisms.

Warner and Heimstra (Reference 11) found that background complexity and noise can increase detection times for visual tasks. Leibowitz in two studies (References 12 and 13) found that a demanding central task can reduce visual sensitivity, while task complexity, heat, and inexperience can reduce the visual field and impair visual perception.

Other recent studies include analyses of vigilance problems (Teichner, Reference 14) and overall stress (Kennedy and Coulter, Reference 15).

Obviously, the preceding discussion has merely scratched the surface relative to studies of visual performance. Vision is the major source of information in boating and the sense under direct test in VAST. However, there is a great deal of research in other senses that may be important in boating (audition, proprioception, etc.) and other stressor effects. For example, one recent study (Dowd, et. al., Reference 16) has shown that fatigue may lead to a greater incidence of motion sickness. Thus, summarizing all the appropriate literature would be an enormous task. Much of this research has been done on simulators and in laboratories; thus, some of the results may not be directly applied to real-world circumstances. In addition, few of these researchers have studied more than one stressor at a time. A more detailed account of the literature and its meaning (especially as related to divided attention tasks) can be found in Stiehl and Miller (References 17 and 18). What may be of more direct benefit are the experimental approaches and designs used in the studies of stress.

For several years, one fruitful approach to stressor effects has been to study divided attention tasks. These are tasks where, essentially, the subject is asked to do two or more things at once. The well-known children's game of patting oneself on the head while rubbing one's stomach is an example of such a task. In psychological experiments involving stressors, these tasks typically involve mental manipulations. The general paradigm is to ask the subject to perform at a specified level on one task (the "primary task") and to do as well as possible on another task (the "secondary task"). Variations from this paradigm are endless. One can introduce stressors, demand the same performance as always on the primary task, and look for a degradation of performance on the secondary task due to the presence of the stressors. The greater the degradation, the greater the influence of the stressors. Thus, performance on the secondary task could be used as a measure of stressor effects. Although there are other variations on this experimental paradigm, the one described above suits the purpose of investigating stressor effects. How can this technique be implemented in boating? The next section describes the VAST apparatus and experimental design.

2.4 VAST Apparatus and Experimental Design

The previous section identified the divided attention task approach as one with great potential in investigating stressor effects in boating. To a boater, the primary task is to operate the boat safely, keep it on course, and head for his destination. The problem is to come up with a secondary task. This is primarily what the Visual Alertness Stressor Test (or, VAST) is. It is a secondary task that will allow stressors to be introduced and provide performance measures such as response times and error rates. One common usage of a secondary task, and the one that was developed for this stressor research, is to use the performance measures to document continued good performance on the primary task while observing correlations between performance on the secondary task and experimental manipulations. VAST satisfies these requirements.

2.4.1 VAST Apparatus

The design for the VAST apparatus included the use of the steering of the boat as a primary task and a signal (or target) display and response in the boat cockpit as the secondary task. The subject was required to steer the boat on a course dictated by the experimenter and do as

well as he could at responding appropriately to certain target displays (signals). The display chosen was a 190° ring of thirty-nine lights (5° spacing between lights). The display was designed to cover a wide range of visual angles, extending well into the peripheral field of vision of the operator. The light ring was covered to put the lights in a shadow and the entire housing was painted flat black. This made the lights visible even in bright sunshine. The lights that were used were standard automobile accessory lights (comparable to bright brake lights).

The display was mounted around the cockpit of the 17 ft (5.2 meters) runabout as shown in Figure 2-2. The cockpit itself was also adapted to provide adequate controls and displays for the subject and the experimenter. The throttle and response button were mounted on the subject's right-hand side, and all subjects were right-handed. The response button was a three position power trim button on the thumb side of the throttle handle. Depressing the button in either direction constituted a response. Figure 2-3 shows the cockpit as viewed over the subject's right shoulder. His right hand is on the throttle and response button. The horn in the photograph was used to signal the subject that he was off course. Below and just to the left of the horn is the tachometer. The subject was instructed to maintain a setting on this instrument but was allowed to change speeds in order to avoid other boats and bridges, to execute a course change, or to slow down if the wave conditions would not permit running at that speed. Directly in front of the steering wheel is the compass. The experimenter verbally called out courses which the subject was to maintain. The horn was blown at the experimenter's discretion. His tolerance was based upon the present conditions, the subject's responses (was he trying to get on course?), and our estimates from the training trials that most subjects could maintain a heading within five degrees.

The "happy face" (operated by a windshield wiper motor) was displayed whenever a subject responded correctly. When an incorrect response was made, the throttle vibrated and an auditory "error" buzzer sounded. These feedback cues were introduced in VAST-2. At the conclusion of VAST-1, the analyses of the data revealed that several subjects responded more than once to the same signal and two subjects had considerable difficulty in mastering the tasks. The introduction of feedback cues in the second VAST experiment was designed to facilitate learning (subjects learn faster when they know which responses are correct or

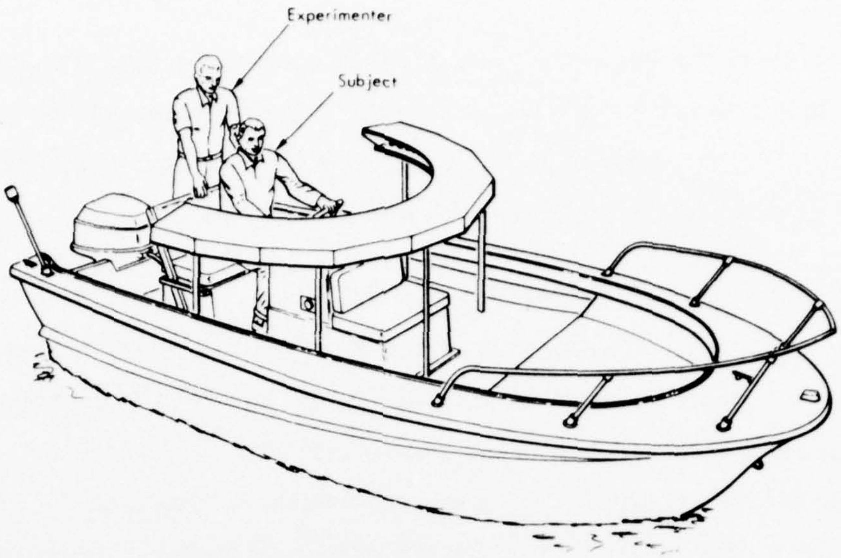

FIGURE 2-2. EXPERIMENTAL APPARATUS:
VISUAL ALERTNESS STRESSOR TEST (VAST)

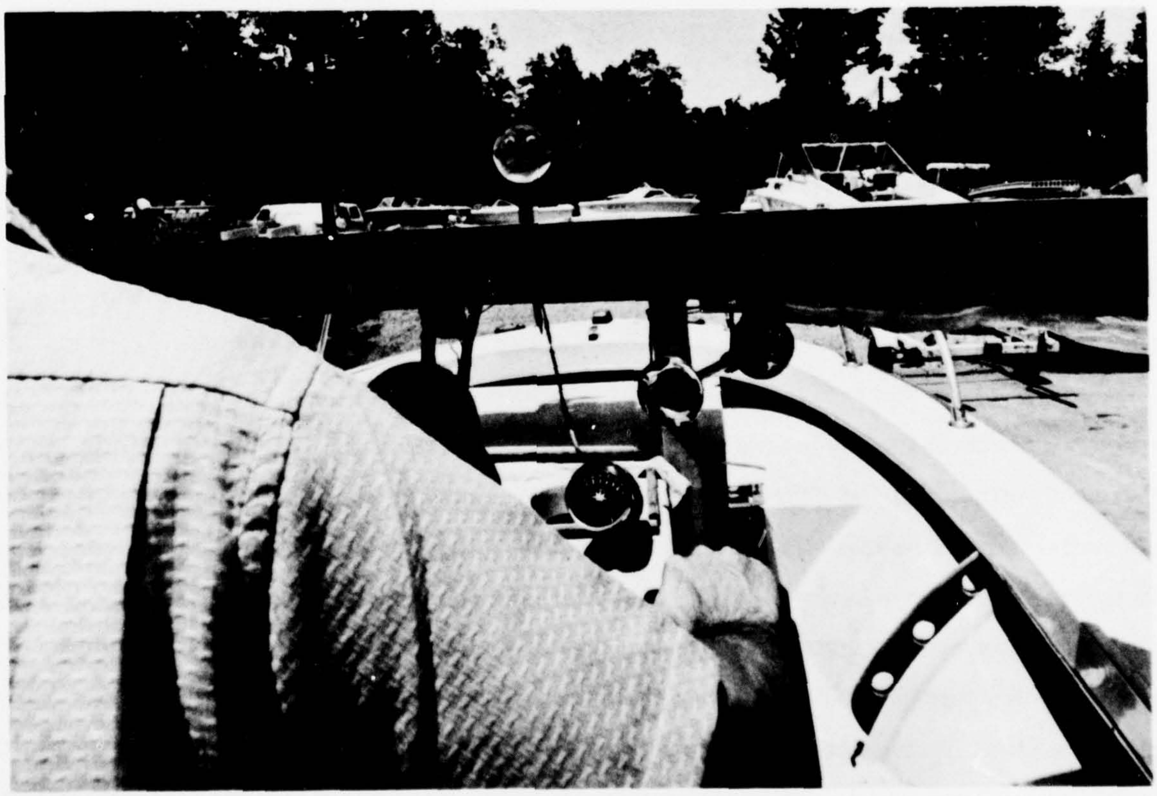

FIGURE 2-3. VAST COCKPIT

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incorrect) and reduce the frequency of repeated responses to the same stimulus. Sometimes the second response to a stimulus would be an error if the light went off just prior to or during the response. With the "happy face," the subject knew his first response had been logged on tape as a correct one and there was no need to respond again.

The VAST apparatus presents the subject with light displays controlled by a mini-computer while the experimenter is dictating a course that the subject is trying to steer. This is the primary task. The secondary task (the light display) is controlled by computer programs. The programs were designed to test the subject's peripheral vision, frontal vision, and information processing capabilities. Light patterns were programmed on three separate channels of the computer, right-to-left, left-to-right, and stationary, describing the movement of the corresponding patterns on the display. The channels were programmed independently, but the light patterns that were presented to the subject may have involved two or more of these channels at once. The simplest pattern that was presented was a single light coming on steady for ten or twenty seconds. This could have been any of the thirty-nine lights, and the subject should have responded to any "non-moving" light, one that was always stationary, or one that was "moving" but stopped. The moving light patterns came from the left-to-right and right-to-left channels. The channel may have turned on any light (say, No. 25) and moved in the appropriate direction (say, right-to-left) for any number of lights at either of two speeds (either one light per second, or one per every one-half second). When the movement stopped, the light may have gone off, or it may have stayed on for ten or more seconds (in which case the subject should have responded as soon as he sensed that the light was on but no longer moving). Since the three channels are independent, many light patterns were possible. The lights could move back and forth across the display (as if they represented a sailboat tacking), or several individual patterns could happen at once or in succession. Thus, the subject may have had to respond to several fixed lights in one pattern, some stationary and some moving lights that have stopped. His attention may have been drawn to one side of the display by a moving sequence while a stationary light came on in another part of the display. Not all displays should have been responded to. On occasion, one or more moving sequences may have been displayed which never stopped at a fixed position before terminating. The subject was not supposed to respond

4/9

FIGURE 2-5. VAST UNDERWAY

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to these, but only to non-moving lights. A response to a moving light was an error. Likewise, failing to respond to a non-moving light was an error. Thus, a "signal" was any non-moving light, and a "non-signal" was any other light pattern. Only signals were to be responded to.

It is readily apparent that the possible combinations were endless. Those that were used were designed to simulate (remotely) the movements of boats and objects on the water and to be sensitive to mental fatigue as induced by the stressors. The timing between patterns varied from approximately one minute to almost eight minutes. Thus, the subjects never knew when a pattern was coming. Several test programs were written (plus a practice program) to prevent the subjects from memorizing test patterns from one test to another.

The cartoon (Figure 2-4) captures the essence of the subject's impression of VAST, while the photograph in Figure 2-5 shows a VAST test underway with a pattern on the display.

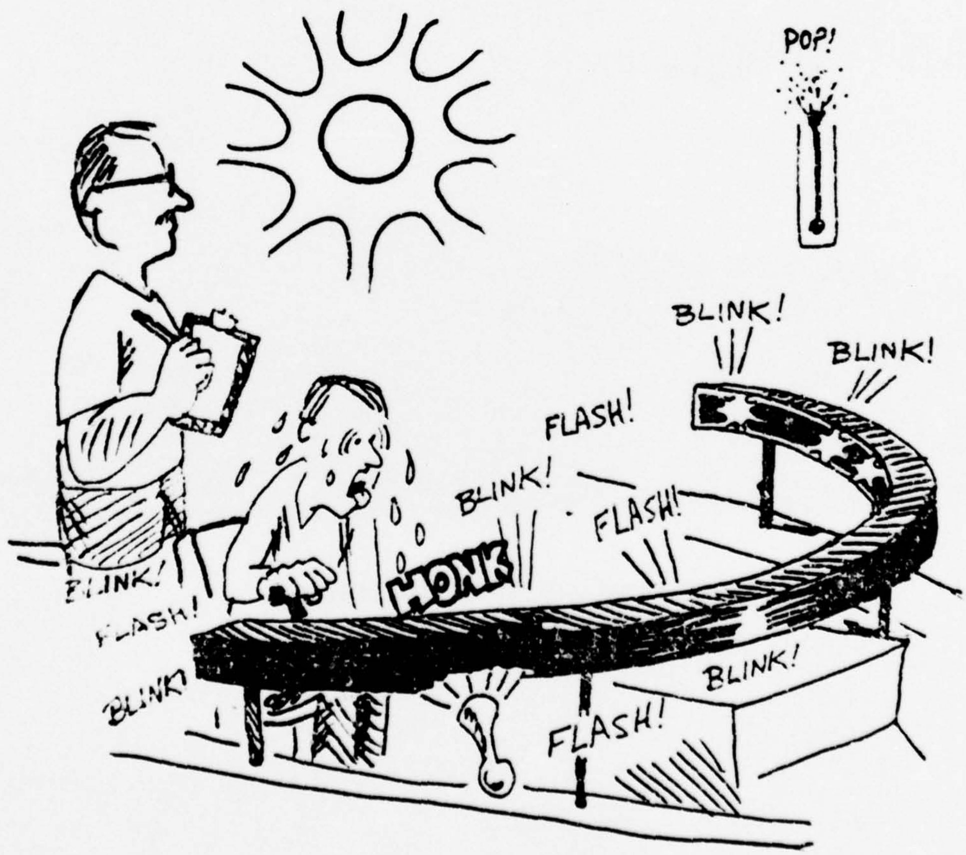


FIGURE 2-4. CARTOONIST'S VIEW OF VAST

2.4.2 Experimental Design

In succeeding sub-sections, the design parameters for each individual experiment will be outlined. The typical sequence of events for each subject is shown in Table 2-1.

TABLE 2-1. OVERALL VAST SEQUENCE OF EVENTS

Preliminaries (obtaining desired physical and mental conditions, ingesting alcohol, etc.)

First VAST run(s) (gaining "rested" data)

Fatigue Cyle (same as preliminaries, with various additional activities)

Second VAST run(s) (gaining "fatigued" data).

In each experiment, stressors, programs, and other factors were counterbalanced as much as possible. Subjects were always as practiced as possible on VAST to minimize learning effects. The subjects were all males, relatively young (between 20 and 39 years old) and right-handed.

The experimental designs were factorial designs (as much as possible) to allow for analyses of variance to account for the effects of individual stressors and stressor combinations (when stressors were manipulated individually).

For a pictorial description of the components of the VAST apparatus, the reader is referred to Reference 1. The individual experimental designs are outlined in succeeding sections.

2.5 VAST-1

The initial VAST experiment (run off the coast of Sanibel Island, Florida, in April, 1975) involved a 2 x 2 factorial design. Two levels of fatigue were used and two types of fatigue. Subjects were tested in a "rested" condition and a "fatigued" condition. Some subjects were exposed to the type of fatigue that might be associated with a "family boating outing" (mostly exposure to sun, heat, glare, and some light physical activity), other subjects went through some activities that might be associated with a "fisherman's outing" (including exposure plus drifting on the water and some added activities in a boat under power). The subjects were

tested in the morning (rested) and after three hours of exposure to stressors according to one of the scenarios just described (fatigued). The two fatigue levels crossed with two types of fatigue constituted the 2 x 2 factorial design. The performance measures taken were the number of significant deviations from course, the response times of the subjects, and the number of errors in the VAST task (both responses to inappropriate light patterns and "missed" patterns).

Results of the VAST-1 experiment showed that reaction times of the fatigued subjects were twice as long as those of rested subjects. The mean response time for rested subjects was 2100 milliseconds (to the nearest 100 milliseconds), and the mean response time when fatigued was 4000 milliseconds. More important was the fact that subjects missed ten times as many signals when they were fatigued. This was not just a delay in their response, but no response at all. The fatigue or stressor effect may be one reason why so many collision victims say, "I never saw the other boat" or, "He didn't have his lights on."

Since the experiment was designed to test for fatigue effects and stressor effects, learning by the subjects during the experiment could contaminate the results. If a subject's response times did not increase under fatigue, was this due to the lack of stressor effects, or the fact that the stressor effects were counteracted by improvements due to learning how to respond to the VAST apparatus? Obviously, the subjects must learn how to respond before the experiment. For this reason, each subject had a one-half hour practice session on the VAST boat under test conditions, with stimuli similar to test stimuli, before his test day. It was not known, before running VAST-1, how much practice would be appropriate or feasible.

The eight subjects were all male Coast Guard personnel. They were between 5'8" (1.77 meters) and 6'3" (1.91 meters) tall, and between 155 and 235 lbs (70 to 106 kg). The subjects ranged in age from 23 to 39; they all knew how to swim; and they all had some boating experience (most of them had more than 100 hours of power boating experience).

The subjects were broken into two groups. One group went through a "family" type of fatigue scenario, and the other experienced a "fisherman" oriented fatigue schedule. The experiment began for each subject with one hour of preparatory activities. These activities were designed to include the general types of activities that a boater would undergo prior to going on the water, including driving on roads and highways with the boat trailered behind, and launching

the boat from a marina launch. After the one hour of preparatory activities, the subject drove the VAST boat for an hour on a course determined by the experimenter. While navigating this course, the subject would be exposed to the computerized light displays. This constituted his first (rested) VAST test. The next three hours for this subject involved general exposure to the elements. For those in the "family" group, the three hours included shelling, playing softball, sunning, walking, and a little running. Lunch was also eaten during this period. These activities were chosen to simulate the kinds of things one might do if he had driven for an hour to a location for a family outing (see Figure 2-6).

<table>
<tr><th>TIME</th><th>SUBJECT 1</th><th>SUBJECT 2</th><th>SUBJECT 3</th><th>SUBJECT 4</th></tr>
<tr><td>8:30 - 9:30</td><td>Preparatory Activities</td><td></td><td rowspan="2"></td><td rowspan="3"></td></tr>
<tr><td>9:30 - 10:30</td><td>VAST TEST # 1</td><td>Preparatory Activities</td></tr>
<tr><td>10:30 - 11:30</td><td rowspan="3">Fatigue Scenario + Lunch</td><td>VAST TEST # 1</td><td>Preparatory Activities</td></tr>
<tr><td>11:30 - 12:30</td><td rowspan="3">Fatigue Scenario + Lunch</td><td>VAST TEST # 1</td><td>Preparatory Activities</td></tr>
<tr><td>12:30 - 1:30</td><td rowspan="3">Fatigue Scenario + Lunch</td><td>VAST TEST # 1</td></tr>
<tr><td>1:30 - 2:30</td><td>VAST TEST # 2</td><td rowspan="3">Fatigue Scenario + Lunch</td></tr>
<tr><td>2:30 - 3:30</td><td rowspan="3"></td><td>VAST TEST # 2</td></tr>
<tr><td>3:30 - 4:30</td><td rowspan="2"></td><td>VAST TEST # 2</td></tr>
<tr><td>4:30 - 5:30</td><td></td><td>VAST TEST # 2</td></tr>
</table>

FIGURE 2-6. EXPERIMENT SCHEDULE FOR VAST-1 (ONE DAY)

Almost half of the fatigue cycle time was spent in resting or semi-resting activities, but in the sunshine. No sunglasses were worn. For the subjects in the "fisherman" group, the three hours were spent in water-related activities. These subjects spent the three hours in the sun,

but on the water. The first two hours they alternately motored one-half hour and drifted one-half hour. The third hour was spent riding in the bow of the VAST boat as another subject was making the test run. In Figure 2-6, the hour spent in the bow of the boat would be the one just prior to VAST Test No. 2 for each subject. Finally, after the three hour fatigue scenario, each subject took the VAST test again, this time in a fatigued state. Test programs were counterbalanced across conditions so that: 1) subjects could not memorize the programs, and 2) if one program happened to be more difficult than another, this would not fortuitously prejudice the data.

Response times, responses, and light patterns were recorded as the primary data. These measures allowed the major questions of the experiment to be answered via changes in response times and error rates, and an analysis of the types of errors made. The temperature and wind velocity were recorded periodically to document weather conditions.

Computer failures due to the shock, vibration, and heat led to an analysis of only the missed signals (and <u>not</u> the responses to non-signals) in the data from trials when the subjects made errors. The missed signals are tabled below by experimental condition. The response time data from two subjects had to be discarded because one subject never mastered the task and another showed severe learning effects in his data. A detailed accounting of these considerations can be found in Reference 1.

TABLE 2-2. NUMBER OF MISSED SIGNALS

	"Family" Stress	"Fisherman" Stress
Morning	0	1
Afternoon	3	7

The number of missed signals for each test run was converted to the proportion of missed signals for that run and transformed by the formula below to enable an analysis of variance. In the transformation, X represents the proportion of missed signals during a test run and X^1 is the transformed proportion which is the total number of signals. This transformation stabilizes the variations in the proportions. Its use is discussed in Reference 19, pages 399-400.

$$X^1 = 2 \arcsin \sqrt{X + 1/2n} \qquad (2-1)$$

An analysis of variance for a multi-factor experiment with repeated measures was performed on the transformed error porportion data. The results (Table 2-3) show that the differences in the proportion of missed signals were statistically significant at the .01 level, with fatigued conditions resulting in significantly more errors than non-fatigued conditions. The other differences (between types of fatigue) were not significant, and the F ratio for the interaction between fatigue level and type of fatigue was relatively small (and not statistically significant).

TABLE 2-3. F-TEST ON PROPORATION OF MISSED SIGNALS: SUMMARY TABLE

Source	Sum of Squares	d.f.	Mean Square	F
Type of Fatigue	15123	1	15123	.278
$Error_1$	217509	4	54377	
Fatigued vs Rested	285208	1	285208	28.10, $p<.01$*
Interaction	58521	1	58521	5.77, $p>.05$
$Error_2$	40596	4	10149	* significant
Total	616957	11		

Table 2-4 shows the summary table for an F-test (see glossary) performed on the response times (in milliseconds). Since the subjects each had a different number of stimuli, an analysis of variance for a multi-factor experiment with repeated measures was used in the F-test computations (see Reference 19, page 397ff).

TABLE 2-4. F-TEST ON RESPONSE TIMES: SUMMARY TABLE

Source	Sum of Squares	d.f.	Mean Square	F
Type of Fatigue	22,274	1	22,274	.014
$Error_1$	6,239,545	4	1,559,886	———
Fatigued vs Rested	8,702,330	1	8,702,330	19.51 $p<.025$*
Interaction	670,714	1	670,714	1.50
$Error_2$	1,784,043	4	446,011	———
Total	17,418,906	11		* significant

The results of the response times were essentially the same as the results for the error scores; i.e., there was a significant effect of exposure to the stressors, but there was no interaction effect between fatigue and type of fatigue nor was there a significant effect of the type of fatigue scenario alone (family versus fisherman). This last fact means that the components that the two fatigue scenarios had in common were the important ones; these caused the overall fatigue effect. The components where they differed had no apparent effect. Thus, the elements of fatigue which collectively seemed to have an effect were glare, heat, noise, vibration (during the test runs), wind, water conditions (during the test runs), and the VAST tasks. The elements which did not have an effect were the drifting, motoring on the "fisherman" boat, and riding in the bow, as opposed to the very light exercise on the beach by the "family" stressors group. The noise, shock, and vibration suffered while underway in the VAST boat were common elements for all subjects and may have had an effect. The noise, shock, and vibration suffered by those in the "fisherman" scenario during their fatigue cycle had no measurable different effect on performance than the light activities on the beach for the "family" group. Thus, the fatigue effect appears to be less dependent upon physical demands, since the irrelevant parameters were the more physical ones. It is possible that a major component to fatigue is a degradation in information processing, because the light activity and exposure had the same gross effect as the activity of the fisherman's scenario.

The lack of an interactive effect further confirms these ideas. The elements of the two fatigue scenarios that were shared had a consistent and statistically significant effect. The mean response time when rested was 2100 milliseconds. The mean response time when fatigued was 4000 milliseconds (to the nearest 100 milliseconds) regardless of the type of fatigue. The same kinds of fatigue effects were found in the error scores. In neither case did the type of fatigue or the interaction of the type of fatigue with level of fatigue have any effect. Thus, the fatigue effect in this study was clear cut, important, and not complicated by interactions. This fact speaks well for the sensitivity of the apparatus and experimental design.

Many studies were referred to in the background literature section that found alcohol results in degradations in response time performance on the order of 100 to 500 milliseconds. In VAST-1 the degradation due to fatigue was on the order of 2000 milliseconds. All of the previous experiments involved laboratory or simulator testing of the effects of relatively high quantities

(0.10% BAC and higher) of alcohol, and yet, none of their results approached the nearly 2000 milliseconds effect of fatigue that was found in this initial VAST experiment, although the adding of eye movement time, central processing time, etc., may correspond to this total effect. Another interesting comparison involved the feelings of the subjects about their performance. With alcohol, subjects often felt as if they performed better than without alcohol. In our experiment one subject commented that he thought he had done better in the afternoon (fatigued) even though the data show degraded performance in the afternoon. This is one of the dangerous aspects of stressors; the subject may believe his performance is improved when it is, in fact, impaired.

The two important findings of VAST-1 were: 1) that the combined daytime stressors (heat, glare, etc.) did have an effect on performance, and 2) the VAST apparatus and experimental paradigm were sensitive to the effect.

Several apparatus modifications resulted from VAST-1, including the addition of feedback to the subject as to whether his responses were correct or incorrect, and a signal to the experimenter and subject as to when the program ended.

2.6 VAST-2

The VAST-2 experiment was designed in an attempt to provide performance data concerning alcohol as a stressor in boating which could be related to the fatigue results. The VAST apparatus was modified to include subject response feedback and an indication to the experimenters as to when the program had terminated.

The VAST-2 alcohol study was performed in August, 1975, in Huntsville, Alabama. Eight male subjects were used in a 2 x 2 factorial design (two levels of fatigue and two levels of alcohol). The eight subjects in the alcohol study were divided into the control group (0.00% BAC) and the experimental group (0.10% BAC). Each subject experienced a sequence of activities very similar to that used in the fatigue study in Sanibel. Each subject was tested, then alternated between fatigue and rest cycles for three hours, then tested again. The alcohol group was allowed one to one and a half hours to drink enough alcohol to attain 0.10% BAC before each test. The data observed were the subjects' response times to the light patterns and the subjects' error rates (missed signals; responses when no signal was present).

There was difficulty in getting the subjects to comparable BAC levels. For the non-fatigued runs, the four alcohol subjects ranged from slightly less than 0.10% BAC to more than 0.14% BAC. Thus, the subjects were not equally exposed to alcohol. The fact that the alcohol subjects had to have time to drink, and had to drink indoors (because of local laws) meant that they experienced less exposure to heat, glare, wind, and other stressors than the control group. Thus, they did not experience fatigue to the same degree. The interaction between fatigue and alcohol is illustrated by the data in Table 2-5. In the morning tests (no fatigue), alcohol led to an increase in the response times. (The data were scaled using a logarithmic transformation to normalize the positively skewed distribution of response times (see Reference 19, pages 400-401); these data were more positively skewed than the response times in VAST-1.) Similarly, fatigue led to an increase in response times, on the average, for the control group. However, the interaction (fatigue and alcohol) resulted in data similar to the data from no fatigue and no alcohol. This indicates that either the alcohol and fatigue effects interact, or the alcohol group was not fatigued, or both. The alcohol group was resting while drinking, thus they probably did not suffer from fatigue. These subjects may have adapted to their drunken state during the day. In addition, it was not easy to replicate their morning BAC's precisely in the afternoon. Some data were lost due to a failure in the data recording system, and this further hampered efforts to analyze the results of this experiment, especially in terms of errors. Only missed signals could be analyzed since the data recording failure precluded identification of errors when the subject responded in the absence of a signal.

TABLE 2-5. INTERACTION BETWEEN FATIGUE AND ALCOHOL: VAST-2

Mean Response Times (in milliseconds)	No Alcohol	Alcohol
No Fatigue (Rested)	1795	2143
Fatigued	2173	1968

The fatigue effects in this experiment were due to the subjects being exposed to glare, heat, light exercise, exposure to the morning VAST test, and general exposure. The environmental factors (weather) were not as severe in Huntsville as they had been in Sanibel in the first VAST experiment in terms of temperature and humidity. One subject's data were deleted because the

fatigue effects would be confused with a large change in this subject's BAC from morning to afternoon. With his data excluded, a comparison was made between morning and afternoon transformed response times for the remaining subjects.

The statistical test (a t-test, see glossary) revealed that fatigue was a significant stressor in the Huntsville study, as it had been in Sanibel ($t = 6.14$, $df = 174$, $p < 0.001$). In terms of response times, the effect of fatigue was an increase in the average latency of a response from 1832 msec rested to 2023 msec fatigued.

Pooling data across subjects within the control and alcohol groups, results in a comparison between rested alcohol and rested non-alcohol groups. The statistical comparison shows a significant difference between these two sets of data ($t = 3.69$, $df = 114$, $p < 0.001$). It must be remembered, however, that this comparison is based on incomplete data samples. The effect depicts a significant degradation in performance due to alcohol. This result reflects an average change in response time from 1858 msec (sober) to 2143 msec (0.10% BAC).

In addition to the comparison of performance levels when the subjects were sober and when they had attained 0.10% BAC, two other small sets of data were collected concerning alcohol. One of the controls underwent a VAST run at 0.75% BAC when fatigued. This combination of fatigue and alcohol led to a significant decrement in his performance, as his mean response time increased from 2529 msec (fatigued, no alcohol) to 3672 msec (fatigued, 0.075% BAC). The subject who had attained 0.14% BAC in his morning run provided data on that high level of alcohol. In his afternoon trial, his BAC was 0.098%. A statistical test was performed on this subject's data, comparing his response times at 0.098% BAC with those at 0.14% BAC. The results are that the increase in BAC to 0.14% is statistically significant ($t = 1.69$, $df = 40$, $p < 0.05$). The effect was to increase this subject's response times, on the average, from 2065 msec (0.098% BAC) to 3062 msec (0.14% BAC). The data from these two subjects represent a small sample, and are merely indicative of the relationship between blood alcohol concentrations and performance. They do suggest that the changes in performance occur at various BAC levels, that the changes may be continuous, and that any increase in BAC, whether from 0.00% or from 0.10%, can lead to a degradation in performance.

The interaction effects described at the beginning of this section indicate that further experimentation is needed to determine the true nature of the interaction between fatigue and alcohol. The data discussed above further suggest that other alcohol levels be investigated. The major conclusions of this study were that fatigue and alcohol are stressors that lead to significant degradations in performance. The significance levels of the fatigue and alcohol effects were very similar (both better than 0.001), and the sizes of the effects were almost the same. The fatigue result was interesting in that the activity levels of the subjects were not greater than those that might be witnessed on a typical outing.

In VAST-2 the fatigue effect observed in VAST-1 was confirmed and alcohol was found to be a significant stressor. The mean response times from VAST-2 were typically faster and the distributions of response times contained less variation than those from VAST-1. This points out one important aspect of research using indirect measures and simulations — such as VAST. VAST does not measure "boating performance" or "the probability of a collision." It is merely a measure of visual alertness and quick response capability while performing a simulated boating task. People do not typically drive their boats on compass headings as dictated by a passenger, with horns and flashing lights, etc. Thus, the actual magnitudes of the measured differences in response times are not important in themselves. There is, at present, no way to relate these magnitudes to actual boating performance except by deduction and inference. Section 2.8 presents a discussion concerning the inference that response times on VAST tend to underestimate the true magnitude of stressor effects in boating in "real time." With experimental verification of the detrimental effects of the stressors that are common to the boating scene, the logical "next step" was to break the fatigue factor down into smaller components. The thrust of the stressor test that followed was to: 1) break down fatigue into smaller components and analyze these (glare, noise, shock/vibration, fatigue), and 2) investigate alcohol effects and the interactions of the various stressors, particularly with alcohol.

It was at least theoretically possible to isolate each of these stressors and run tests on each one independently, or two at a time. This approach had merit from the standpoint of simplicity of experimental design and the potential for investigating any particular stressor in depth. However, such an approach is costly in time and money, and it does not allow the study of interactions between stressors. A boater is seldom exposed to stressors one at a time. He encounters a complex environment on the water which can affect him in many ways.

A better approach appeared to be one that studied several stressors at once. This was accomplished through a factorial experimental design, which allowed analyses of the individual stressors, and the interactions as well. Such an approach was more economical in terms of time and money, and was pursued in VAST-3.

2.7 VAST-3

2.7.1 Introduction

VAST-3 was the attempt to study alcohol, fatigue, noise, shock/vibration, glare and their interactions in one experiment. With the qualified successes of VAST-1 and VAST-2, the objective became clear: analyze the effects of as many of the major stressors in boating as possible.

Through meetings of Wyle and USCG personnel, the design/performance criteria for VAST-3 were determined. These are shown in Table 2-6.

TABLE 2-6. DESIGN CRITERIA FOR VAST-3

1. Get all major effects as soon as possible; prioritize according to factors which can be controlled by USCG.

2. Make a modular design so that if the VAST boat or apparatus fails there is a high probability of accomplishing as much of Objective 1 as possible, given the reduced amount of data.

3. Make the design of the latter portions of the experiment adaptable, so that design decisions can be made contingent upon the results of the first few days. This necessitates the design of a quick data acquisition and analysis program to be implemented after the first few days.

4. The design must reflect the probability of health/availability problems of all personnel and have flexibility to allow for weather or traffic problems.

In VAST-1 and VAST-2 there had been reliability problems with the computer and data recording systems. There were basically two reliability problems with the VAST system:

1) Complete system failure, resulting in shutdown of indefinite length.
2) System foul-up which allows continuation, but results in reduced data per run.

The succeeding sections present the design parameters and results of VAST-3. Throughout these discussions, the reader should remember that this was an attempt to isolate several stressors and stressor interactions in the boating environment within one experiment.

2.7.2 VAST-3 Experimental Design

The design on the following pages satisfied the design criteria. Criteria 1 and 2 were satisfied by the three-day, counter-balanced modular design. Data were collected in all thirty-six conditions in each cycle of three days. Criteria 3 and 4 were satisfied in that the design could have been abandoned or interrupted after any cycle, and an extra subject was available.

The subjects for VAST-3 were all right-handed adult males. The site for VAST-3 was the same as for VAST-1, Sanibel, Florida.

VAST-3 was a five factor, 3 x 3 x 3 x 2 x 2, factorial design. The five factors (variables) and levels under each factor are shown in Table 2-7. Thus, there were 108 data cells to be completed (one for each combination in the design).

TABLE 2-7. VAST-3 VARIABLES

Factor	Subjects	Alcohol	Noise/Shock/Vibration	Fatigue	Glare
Levels	S_1	0.00% BAC	N_1 Low noise, Soft Seat	Rested	Tests run:
	S_2	0.05% BAC	N_2 Normal noise, soft seat		g - With Sunglasses
	S_3	0.10% BAC	N_3 Normal noise, rough seat	Fatigued	G - Without Sunglasses
	3 ×	3 ×	3 ×	2 ×	2

The design included three alcohol levels since this stressor was thought to be very important and VAST-2 had indicated the necessity for studying an intermediate level such as 0.05% BAC. Also, the use of the intermediate level would allow more comparisons with other results (such as fatigue results obtained previously).

Noise, shock, and vibration were combined into one variable in the design. To have done otherwise would have required the violation of design criteria 1 and 2 and lengthened the time required for a completed experiment. Noise was manipulated by having the subjects wear (or not wear) earmuffs which attenuated background noise by 20 dB. The actual noise level on the boat was not measured since the conditions varied from day to day and minute to minute depending upon the weather, speed, water conditions, etc. The speed was maintained as a constant across subjects as much as possible. No other control of noise was used other than the earmuffs. Shock and vibration were manipulated by using (or "locking out") a helmsman's seat (Pompanette H2P16) on an inverted shock pedestal. The "locked out" position negated the effects of the pedestal. The fatigue variable was treated as it had been previously. Thus, the variables were manipulated using commercially available devices (seat, earmuffs, sunglasses - see below - etc.) without attempting to quantify or control precise levels of each. In this way, "real world" exposures were better approximated, and reduced by the manipulations.

The glare manipulation involved the wearing or not wearing of sunglasses on the boat during test runs. No sunglasses were worn during fatigue. Thus, glare was treated as "just another variable." In truth, glare can be treated two ways: one is as a problem on the boat (reflective surfaces, etc.) and water surface, and the other is as a cumulative problem (i.e., as part of fatigue). All of the subjects in this design experienced cumulative glare as part of their fatigue scenario. The cumulative effects were there for everyone. The measurement of cumulative glare could not be included in the major design without violating design criteria 1 and 2. It should be noted that the VAST boat had very few on board glare sources. The light display was flat black, the compass was flat gray-black, the tachometer was black. In fact, the only real sources of glare on board were the bow rail and horn. There was no windshield, windshield frame, etc., as might be found on more typical craft. Thus, on board glare in VAST was minimal.

In fact, none of the variables were treated as cumulative to a greater extent than the duration of the test runs. This experiment was not designed to measure the effect of prolonged (several hours) exposure to noise, for example.

Since so much data (108 test runs) were to be gathered, it was decided that each subject could run four times per day: two "rested" and two "fatigued." A typical schedule for one subject for one cycle of three days is shown in Figure 2-7. Each level of each stressor is defined for each of four test runs for each day.

	Day A	Day B	Day C
Fatigue	Rested	Rested	Rested
Alcohol	.00%	.05%	.10%
Glare	g	g	g
N./S.V.	N_2	N_3	N_1
Fatigue	Rested	Rested	Rested
Alcohol	.00%	.05%	.10%
Glare	G	G	G
N./S.V.	N_2	N_3	N_1
Fatigue Scenario			
Fatigue	Fatigued	Fatigued	Fatigued
Alcohol	.00%	.05%	.10%
Glare	g	g	g
N./S.V.	N_2	N_3	N_1
Fatigue	Fatigued	Fatigued	Fatigued
Alcohol	.00%	.05%	.10%
Glare	G	G	G
N./S.V.	N_2	N_3	N_1

FIGURE 2-7. VAST-3 SUBJECT SCHEDULE (ONE SUBJECT, ONE CYCLE)

With each subject running four times per day, and three subjects, data for twelve sets of conditions could be collected each day. Thus, the completion of all 108 data cells required nine test days (see Figure 2-9). The 108 data cells correspond to thirty-six sets of conditions for each of three subjects (3 x 36 = 108). Thus, with three subjects, each cycle of three days leads to gathering data for each of the thirty-six sets of conditions shown in Figure 2-8. The experiment, then, was broken down into three three-day cycles, with data gathered for all thirty-six sets of conditions in each cycle. Upon the completion of all nine test days (all

three cycles), each subject had run in each set of conditions. Figure 2-7 is an example of just one schedule for one cycle for one subject. Figure 2-9 shows how each subject's data is placed in each data cell during successive cycles of the experiment.

Alcohol	Noise/S.V.	Fatigue	Glare
0.00% BAC	N_1	f (rested)	g (low glare - sunglasses)
0.00% BAC	N_1	f	G (high glare - no sunglasses)
0.00% BAC	N_2	f	g
0.00% BAC	N_2	f	G
0.00% BAC	N_3	f	g
0.00% BAC	N_3	f	G
0.00% BAC	N_1	F (fatigued)	g
0.00% BAC	N_1	F	G
0.00% BAC	N_2	F	g
0.00% BAC	N_2	F	G
0.00% BAC	N_3	F	g
0.00% BAC	N_3	F	G
0.05% BAC	N_1	f	g
0.05% BAC	N_1	f	G
0.05% BAC	N_2	f	g
0.05% BAC	N_2	f	G
0.05% BAC	N_3	f	g
0.05% BAC	N_3	f	G
0.05% BAC	N_1	F	g
0.05% BAC	N_1	F	G
0.05% BAC	N_2	F	g
0.05% BAC	N_2	F	G
0.05% BAC	N_3	F	g
0.05% BAC	N_3	F	G
0.10% BAC	N_1	f	g
0.10% BAC	N_1	f	G
0.10% BAC	N_2	f	g
0.10% BAC	N_2	f	G
0.10% BAC	N_3	f	g
0.10% BAC	N_3	f	G
0.10% BAC	N_1	F	g
0.10% BAC	N_1	F	G
0.10% BAC	N_2	F	g
0.10% BAC	N_2	F	G
0.10% BAC	N_3	F	g
0.10% BAC	N_3	F	G

Note: N_1 = lo noise, soft seat; N_2 = normal noise, soft seat; N_3 = normal noise, normal seat

FIGURE 2-8. VAST-3 EXPERIMENTAL CONDITIONS

		0.00%			0.05%			0.10%		
		N_1	N_2	N_3	N_1	N_2	N_3	N_1	N_2	N_3
Rested	g	S_3 S_2 S_1	S_1 S_3 S_2	S_2 S_1 S_3	S_2 S_1 S_3	S_3 S_2 S_1	S_1 S_3 S_2	S_1 S_3 S_2	S_2 S_1 S_3	S_3 S_2 S_1
	G	S_3 S_2 S_1	S_1 S_3 S_2	S_2 S_1 S_3	S_2 S_1 S_3	S_3 S_2 S_1	S_1 S_3 S_2	S_1 S_3 S_2	S_2 S_1 S_3	S_3 S_2 S_1
Fatigued	g	S_3 S_2 S_1	S_1 S_3 S_2	S_2 S_1 S_3	S_2 S_1 S_3	S_3 S_2 S_1	S_1 S_3 S_2	S_1 S_3 S_2	S_2 S_1 S_3	S_3 S_2 S_1
	G	S_3 S_2 S_1	S_1 S_3 S_2	S_2 S_1 S_3	S_2 S_1 S_3	S_3 S_2 S_1	S_1 S_3 S_2	S_1 S_3 S_2	S_2 S_1 S_3	S_3 S_2 S_1

Note: Data cells filled by subjects (S_1 through S_3) during successive cycles of 3 days.

FIGURE 2-9. VAST-3 DATA CELLS

Figure 2-10 shows how each subject changed schedules (such as Figure 2-7) with successive cycles of the experiment. The asterisks were decision points. At those times: 1) data had been collected for every set of combinations of stressors, and 2) a breakdown in VAST after these points would not preclude analyses of all the major factors. Thus, the schedules and cycles allowed considerable counterbalancing, repeated measures, and satisfaction of the design criteria.

Day 10 designs were derived before and during the actual testing in order to answer questions which might have arisen during the experiment. At the end of the third cycle (Day 9) it was decided that data should be collected concerning cumulative glare. Thus, one subject was run on Day 10 in a condition that he had run previously, except this time he wore sunglasses during fatigue. Thus, the Day 10 data represented a relative lack of cumulative glare when compared to the previous data. In addition, one subject was run in the low noise, high shock/vibration condition on Day 10. This condition had not been run previously.

	S_1	S_2	S_3
Cycle 1 (Test Days 1-3)	Sch. 1	Sch. 2	Sch. 3
Cycle 2 (Test Days 4-6)	Sch. 2 *	Sch. 3 *	Sch. 1 *
Cycle 3 (Test Days 7-9)	Sch. 3 *	Sch. 1 *	Sch. 2 *
Test Days 10+	*	*	*

FIGURE 2-10. VAST-3 SUBJECTS' SCHEDULES

The necessity to run twelve times per day created several modifications from previous VAST experiments. The VAST computer and data collection systems were required to be more reliable than ever before to keep on schedule. They were. The computer programs were rewritten and new programs were added so each run would require only forty-five minutes (as opposed to an hour previously) and so the subject could not memorize the programs during his thirty-six test runs.

The subjects took their two morning runs (and two afternoon runs) "back to back", with the first run being with sunglasses and the second without. This was done so that the glare effects of running without sunglasses would not carry over immediately into another test (which would have happened if the "with sunglasses" run had ever followed the "without").

The day-by-day design, then, was not unlike previous ones with the exception of the detailed treatment of stressors. The subjects each were "treated" (alcohol, seat adjustment, etc., with sunglasses) and run on VAST. They came back, took off the sunglasses and ran again. A three-hour fatigue period consisting of light exercise followed — typically including lunch, continuous exposure to sun and heat, beverages, and horseshoes. Then the morning runs were replicated after the fatigue period. An attempt was made to make sure that all subjects ingested the same volume of liquids and participated in exercises to the same degree.

2.7.3 Data Collection

The collection of data was accomplished in twelve days. Computer and data recording problems caused a one day delay at the end of Cycle 1. At the end of Cycle 2, another day of rest and verification of system integrity was scheduled. Thus, with the completion of Cycle 3 and the Day 10 design, a total of twelve days was required.

There were some minor computer malfunctions which were not detected until the data were analyzed completely. These caused the loss of a few response times. The major computer problems that occurred on two occasions resulted in the rescheduling of some test runs to Day 10 for completion, and the loss of data from one of the 108 data cells. These data were estimated from other data using techniques that are described in following sections.

2.7.4 Results

The experiment was run over the course of approximately two weeks. There were ten actual test days, but two days were lost due to poor weather and/or computer repairs. The results will be reported in three sections: 1) supporting data (weather, alcohol levels, etc.), 2) response time data, and 3) error data.

2.7.4.1 Supporting Data — The supporting data include recordings of the temperatures and weather information at the test site, recordings of the BACs attained by the subjects, and the recorded system performance on tape.

2.7.4.1.1 Weather Data

The temperature at various times during the day were recorded for each of the ten test days. These data are shown in Table 2-8. No tests were run after 1400 on Day 10, thus, no weather data were recorded for that afternoon. The high temperatures ranged from 75°F (23.9°C) (Days 5 and 6) to 87°F (30.6°C) (Day 10). The temperature range each day was usually around 15° during testing hours. Skies ranged from partly cloudy to clear. Winds ranged from relatively calm (0-5 mph (0-8 kph)) to moderate (10-20 mph (16-32 kph)), with the heavier winds accompanying the cooler days. Humidities were not uncomfortable, although they varied from day to day also. In general, the only uncomfortable weather occured early on Days 5 and 6 when it was relatively cool and windy. Weather effects are obviously important in this task. They can influence

glare, fatigue, shock, and vibration — virtually every stressor other than alcohol. Heat was included in fatigue, as were cumulative glare effects, in this study. These two facets of fatigue, then, were measured but not under direct control. The experiment was designed to minimize the occurrence of weather-induced data effects (see Section 2.7.2) by partially counterbalancing the data collection across days.

TABLE 2-8. WEATHER DATA

Time	Test Day									
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
8:30 a.m.	67	71	73	73	62	58	63	71	69	70
10:30 a.m.	74	77	80	80	70	65	70	79	78	78
12:30 p.m.	81	85	84	80	73	70	79	84	83	87
2:30 p.m.	83	82	84	82	75	75	82	82	83	--
4:30 p.m.	80	81	86	82	71	74	78	80	80	--

Note: All temperatures are in $^{\circ}$F. [$^{\circ}C = 5/9\ (^{\circ}F - 32)$]

2.7.4.1.2 Alcohol Levels

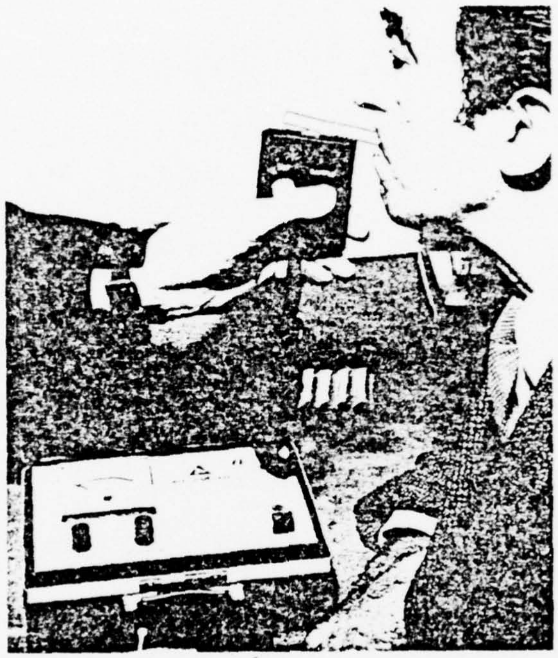
All of the experimental manipulations (sunglasses, seat post, earmuffs) other than alcohol led to well-defined conditions. The alcohol manipulation involved causing the subjects to ingest alcohol and then measuring their BAC. Necessarily, the specification of the alcohol conditions was less precise than the other variables. Table 2-9 shows the measured BACs for each subject between his two morning or afternoon runs.

TABLE 2-9. MEASURED BACS (% OF ALCOHOL IN THE BLOOD)

		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
	S_1	.047	.102	.000	.000	.048	.107	.094	.000	.060	.000
a.m.	S_2	.000	.058*	.095	.114	.000	.050	.050	.102	.000	.047
	S_3	.095	.000	.045	.050	.092	.000	.000	.052	.098	.000
	S_1	.048	.090	.000	.000	.047	.095	.091	.000	.048	.000
p.m.	S_2	.000	.045*	.095	.102	.000	.000*	.050	.095	.000	.050
	S_3	.102	.000	.053	.044	.082	.000	.000	.049	.092	.000

* Note: Some runs from these conditions had to be rescheduled for Day 10.

The alcohol levels were measured using a portable breath analyzer (Alcolmeter, from Intoximaters, Inc., St. Louis) as shown in the picture below. This device is accurate to within $\pm$ 0.01% BAC.



The data reported in Table 2-9 represent the subject BACs between runs. Thus, at the beginning of the first morning or afternoon run, the subject's BAC may have been 0.005 to 0.010% BAC higher than the value indicated, with the BAC falling between then and the test to the measured level. Of course, some alcohol may have been in his stomach (and not yet in the bloodstream) at the outset of the first run, and absorbed during the run. The subjects were given a small amount (on the order of one-half ounce (14.8 milliliters) or less) between runs to maintain their alcohol levels for the second run.

The alcohol data varied around the desired values (0.00% BAC, 0.05% BAC, and 0.10% BAC); the measuring instrument had some intrinsic error, and BACs changed over time during each test run. Thus, the "0.05% BAC data" in succeeding sections actually represent a range of BACs from approximately 0.04% BAC to 0.07% BAC,

while the "0.10% BAC data" represent BACs from approximately 0.08% BAC to 0.12% BAC. Over the course of the experiment, the personnel involved acquired an understanding of each individual and what adjustments to the amount of alcohol ingested were needed to attain a desired BAC level.

2.7.4.1.3 System Performance

The VAST mini-computer, display, system, and data recording system all performed better than they ever had before. Due to several program revisions, design changes, and modifications, the overall system was more complex than in previous experiments. Even with the increased complexity, the system performed well. Some minor computer malfunctions and data recording problems caused delays which resulted in four runs being rescheduled for Day 10 from Day 2 and Day 6. One experimental run was not completed satisfactorily, necessitating the use of data completion procedures outlined in Sections 2.7.4.2 and 2.7.4.3. Over 99% of the conditions for which data were to be gathered were completed. The computer presented the programmed light patterns at the proper time and in correct sequence over 90% of the time. Considering the conditions under which the system was asked to perform (extreme shock/vibration, heat, and twelve consecutive days of exposure to a salt water environment), these results are remarkable. Over all three experiments the VAST system was operational for over 120 hours (including subject practice runs) and over 3600 miles. Approximately seventy of those hours and 2100 miles were logged in VAST-3.

2.7.4.2 Response Time Data — VAST is a visual detection/manual response task. As such, one of the critical measures of performance on the task is subject response times. In all VAST experiments a response time was measured from the onset of the "signal" (one or one-half second after onset of the light) to the initiation of the response (the depression of the response button on the throttle) in milliseconds. The subjects were required to respond to the various light patterns described previously, and twenty signals were presented in each experimental run. Thus, twenty response times were obtained for each run. (In some cases, due to minor computer malfunctions, less than twenty responses were obtained). A total of 2025 response times were obtained for the 112 experimental runs in ten days.

2.7.4.2.1 Learning Effects

In previous studies (References 1 and 2), learning effects were analyzed. In the first VAST experiment, data from two subjects were discarded due to evidence of strong learning effects within test runs in those data. In VAST-3, the subjects were well trained and had more practice on the computerized vessel under test conditions than any previous set of subjects. This fact, plus the careful counterbalancing in the experimental design, tended to reduce the likelihood that unusual learning effects would be present to a great extent. The data tend to support this supposition for individual subjects and the group as a whole. The experimental manipulations produced fast and slow mean response times for tests run on all days. However, the mean times for each subject improved with each cycle of three days, and the mean time overall (for the entire group) improved with each cycle of three days. Table 2-10 shows the group mean times for each cycle. Each subject improved over time and the rates of improvement were 20 to 30% overall.

TABLE 2-10. GROUP MEAN RESPONSE TIMES (IN MILLISECONDS)

Cycle 1 (Days 1-3)	Cycle 2 (Days 4-6)	Cycle 3 (Days 7-9)
2754	2239	2042

There were learning effects, but they were present throughout the data. They do not appear to differentially affect the data under one set of conditions more than under another set. Thus, the learning effects represent an overall trend toward better performance on the part of the subjects. This may partially account for the lack of significant overall fatigue effect and the "reversed" glare effect (explained in the following sections). All other factors were counterbalanced across time.

There were no pronounced learning effects warranting the discarding of data, as there had been in VAST-1. The individual test runs tended to include very short response times in early, middle, and late segments of the individual programs in all cycles of the experiment.

Thus, the learning effects represent overall improvement with practice by the subjects, at all levels of all factors, but the facts that they occurred in all subjects, across all counterbalanced conditions, and were gradual, indicates that the chances that they introduced anomalies in the data (other than those mentioned) are relatively remote.

Since the subjects were still improving their performance in the third cycle (learning) after nearly twenty hours of testing and practice, it is probable that they would have continued to improve gradually over time. This trend probably would have continued until the subjects had memorized all the programs. At that point, learning would discontinue, but their behavior would no longer be of interest, since they could anticipate the light sequences. The behavior that was witnessed was far from this eventuality. The point is that learning effects are not a problem until and unless they affect experimental variables or subjects differentially.

2.7.4.2.2 Analysis of Response Time Data

As in previous experiments there was quite a range of response times. The shortest times were on the order of a minimal reaction time under ideal conditions (about 200 milliseconds), while the longest times were over ten seconds (about 11,000 milliseconds). There were some signals that were not responded to. These were arbitrarily included as 11,500 millisecond response times in the data (slightly longer than the longest true response time). The vast majority of the response times were between 1500 and 3000 milliseconds. In order to perform an analysis of variance on the response time data, the data were scaled using the logarithmic transformation shown in Equation 2-2 to normalize the positive skewness of the distribution of response times (see Reference 19, pages 400-401).

$$X' = \log X \qquad (2\text{-}2)$$

As mentioned previously, one data cell was not completed satisfactorily. The response time mean for this data cell was estimated from the means of other cells in the experiment. (Some techniques for this are outlined in Reference 19, pages 487-490.) Filling in missing data necessarily involves making an assumption about the true data, and sacrificing at least one degree of freedom in the analyses. To fill in the missing

TABLE 2-11. VAST-3 DATA ANALYSIS:
ANOVA FOR RESPONSE TIMES

Source	d.f.	Sum Sq.	F	P	Signif.
S(Subjects)	2	0.383			
A(Alcohol)	2	0.115	10.952	p<.025	Significant
AxS	4	0.021			
G(Glare)	1	0.037	17.097	.10>p>.05	Marginal
GxS	2	0.004			
GxA	2	0.004	0.381	p>.25	Not Significant
GxAxS	4	0.021			
F(Fatigue)	1	0.000	0.000	p>.99	Not Significant
FxS	2	0.036			
FxA	2	0.003	1.200	p>.25	Not Significant
FxAxS	4	0.005			
GxF	1	0.007	16.607	.10>p>.05	Marginal
SxGxF	2	0.001			
FxAxG	2	0.000	0.021	p>.25	Not Significant
FxAxGxS	4	0.022			
N(Noise/Shock/Vib.)	2	0.040	4.877	.10>p>.05	Marginal
SxN	4	0.016			
NxA	4	0.049	0.192	p>.25	Not Significant
SxAxN	8	0.509			
GxN	2	0.031	4.766	.10>p>.05	Marginal
SxGxN	4	0.013			
FxN	2	0.033	5.275	.10>p>.05	Marginal
SxFxN	4	0.013			
NxAxG	4	0.002	0.079	p>.25	Not Significant
NxAxGxS	8	0.062			
FxAxN	4	0.031	0.385	p>.25	Not Significant
FxAxNxS	8	0.160			
NxFxG	2	0.040	2.146	.25>p>.10	Not Significant
NxFxGxS	4	0.037			
FxAxNxG	4	0.156	2.183	.25>p>.10	Not Significant
FxAxNxGxS	8-1=7	0.125			
TOTAL	107-1=106	1.691			

response time mean, it was assumed that there was no five-way interaction between alcohol, glare, noise/shock/vibration, fatigue, and subjects. Thus, in the analyses of variance that follow, one degree of freedom was subtracted from the five-way interaction F tests.

The data in all cells (including missed signals) were reduced to means for each cell. The means were transformed using Equation 2-2, and the data were analyzed.

The response time data for VAST-3 were subjected to an analysis of variance with four fixed factors (glare: two levels, alcohol: three levels, noise/shock/vibration: three levels, and fatigue: two levels) and one random factor (subjects: three). The analysis of variance proceded as outlined in Reference 19, Chapter 7, and Reference 20, Chapter 13.

The results of the analysis of variance are shown in Table 2-11. As mentioned previously, one mean was estimated from other data, thus there were only 8 - 1 = 7 degrees of freedom in the F x A x N x G x S term and only 107 - 1 = 106 degrees of freedom overall. The lack of a significant F x A x N x G interaction indicates that the assumption (of no interaction) used in the data estimation procedure was not contradicted by the data.

The alcohol effect is shown in Table 2-12. The numbers in the table are the mean response times (in milliseconds) for all subjects in all conditions under each alcohol level. The effect is toward longer response times with drinking, except for the 0.05% BAC data. These data must be analyzed in conjunction with the error data in succeeding sections for a complete understanding of the alcohol effect. This is done in Section 2.7.5.

TABLE 2-12. THE ALCOHOL EFFECT IN RESPONSE TIMES

Alcohol Level	0.00% BAC	0.05% BAC	0.10% BAC
Mean Response Time	2304 msec.	2168 msec.	2599 msec.

The glare effect was marinally significant in the "reverse" direction; i.e., the subjects performed better without sunglasses than with them. The glare results are shown in Table 2-13. The discussion of this effect is reserved for Section 2.7.5. It centers on the nature of the glare manipulation and learning effects.

TABLE 2-13. THE GLARE EFFECT IN RESPONSE TIMES

Glare Level:	Wearing Sunglasses	Not Wearing Sunglasses
Mean Response Time	2453 msec.	2252 msec.

Noise/shock/vibration, treated as one variable in this study, was found to have a marginal effect on response times as well. This effect is shown in Table 2-14. The difference between N_1 and N_2 represents the effect of noise (at a low shock/vibration level), while the difference between N_2 and N_3 represents the effect of shock and vibration (at a high noise level). The difference between N_1 and N_3 represents the combined effects of high noise, shock, and vibration.

TABLE 2-14. THE NOISE/SHOCK/VIBRATION EFFECT IN RESPONSE TIMES

N/S/V Level	lo Noise, lo S/V } N_1	hi Noise, lo S/V } N_2	hi Noise, hi S/V } N_3
Mean Response Time	2219 msec	2365 msec	2472 msec

The difference in response times for fatigued versus rested conditions was essentially zero. The lack of a fatigue effect was somewhat unexpected (fatigue had had a significant effect in both VAST-1 and VAST-2), although it is at least partially accounted for in Section 2.7.5 in terms of learning effects.

Only three of the interactions were even marginally significant. These three were the three two-way interactions involving glare, fatigue, and noise/shock/vibration.

The glare by fatigue interaction data are shown in Table 2-15. These data indicate that the glare manipulation resulted in less change in performance under fatigue, and that fatigue had a more detrimental effect when sunglasses were not worn. These effects are at least partially accounted for by learning effects, as discussed in Section 2.7.5.

TABLE 2-15. GLARE BY FATIGUE EFFECT IN RESPONSE TIMES

		Fatigue Level	
		Rested	Fatigued
Glare Level	With Sunglasses	2498 msec.	2409 msec.
	Without Sunglasses	2211 msec.	2293 msec.

Note: Data are mean response times.

The glare by noise/shock/vibration interaction is depicted by the data in Table 2-16. This interaction appears to be complex: 1) noise had very little effect when sunglasses were not worn, while shock/vibration did, and 2) noise and shock/vibration together had less effect when sunglasses were worn than noise alone. Thie interaction cannot be fully understood unless error data are included in the analysis (see Section 2.7.5).

TABLE 2-16. GLARE BY NOISE/SHOCK/VIBRATION EFFECT IN RESPONSE TIMES

		N_1 {lo Noise, lo S/V}	N_2 {hi Noise, lo S/V}	N_3 {hi Noise, hi S/V}
Glare Level	With Sunglasses	2295 msec.	2600 msec.	2473 msec.
	Without Sunglasses	2148 msec.	2152 msec.	2470 msec.

Note: Data are mean response times.

The fatigue by noise/shock/vibration interaction data are tabled below. These data tend to indicate that noise had a relatively small effect when the subject is rested, while the addition of shock and vibration had a larger effect. On the other hand, noise had a large effect when fatigued, and the addition of shock and vibration had about the same effect as it had when rested.

TABLE 2-17. FATIGUE BY NOISE/SHOCK/VIBRATION EFFECT IN RESPONSE TIMES

		N_1 {lo Noise, lo S/V}	N_2 {hi Noise, lo S/V}	N_3 {hi Noise, hi S/V}
Fatigue Level	Rested	2350 msec.	2291 msec.	2411 msec.
	Fatigued	2097 msec.	2442 msec.	2534 msec.

Note: Data are mean response times.

None of the other two-factor interactions were significant, and none of the higher order interactions were significant.

The Day 10 test runs were supposed to give indicative data in two areas of possible future interest (and included a few runs to make up for data that could not be collected earlier). One of the subjects ran under conditions very similar to those used in the first nine test days, except he wore the earmuffs and rode in the rough seat configuration (0.00% BAC, rested and then fatigued, with sunglasses, low noise, high shock/vibration). These data, when compared with low noise/low shock/vibration data under the same conditions, would be indicative of the effect of shock/vibration alone (under low noise conditions). The data are by no means conclusive, but they do suggest that shock and vibration (apart from noise) may be important in performance (see Table 2-18).

TABLE 2-18. DAY 10 NOISE/SHOCK/VIBRATION MANIPULATION

	Rested	Fatigued
Mean, All S's (0.00% BAC, low glare, lo noise, lo S/V)	2613	2413
Day 10 (0.00% BAC, low glare, lo noise, hi S/V)	1905	3020

Note: Data are mean response times in milliseconds.

A second Day 10 manipulation involved having one subject wear sungalsses all day. There are two ways that glare may be conceptualized: 1) as a short-term factor, such as being exposed to a glare source only while traveling into the sun, and 2) as a long-term or cumulative factor, such as the degradation in performance due to several hours

of exposure to various glare sources. In the three-cycle, nine day experiment, the comparison of "with sunglasses" versus "without" was an attempt to measure short-term glare effects due to glare sources on the boat. All of the subjects were exposed to the sun during their fatigue periods. Thus, they all experienced cumulative glare effects. On Day 10, one subject wore sunglasses all day, so he did not experience cumulative glare effects to the same extent. His data are shown in Table 2-19 with the comparative data from the experiment. These data indicate that wearing sunglasses all day may have led to an improvement in performance.

TABLE 2-19. DAY 10 CUMULATIVE GLARE MANIPULATION

Same subject, 0.00% BAC, high noise, high shock/vibration, afternoon (fatigued), wearing sunglasses during test:

No sunglasses during fatigue: Cumulative Glare	Sunglasses all day: No Cumulative Glare
2291 msec.	1738 msec.

Note: Data are mean response times.

The next section presents the results in terms of errors, and is followed by a discussion of all the results and their meaning.

2.7.4.3 Error Data — There were two types of errors that could be made on VAST: 1) the subject could have failed to respond to a light pattern that he should have responded to (he "missed" a "signal"), or 2) the subject could have responded to a light pattern that he should not have responded to (he made a "false alarm").

In previous studies (References 1 and 21), the error data that were considered were the occurrences of missed signals. The proportions of signals that were missed were determined for the experimental conditions. These data were then transformed using an arcsine transformation and an analysis of variance was performed. In these previous studies, a detailed analysis of false alarms was not possible because of problems with the VAST computer. It was not possible to identify every false alarm response and the pattern that was responded to. However, in VAST-3 such analyses were possible, and are completed here.

2.7.4.3.1 Signal Detection Theory

The theory of signal detection in psychology has been developed over the past twenty years to systematize knowledge in the field of psychophysics. It provides the means of analyzing the behavior of the subject in decision/detection experiments (see Reference 22). One of the behavioral measures derived from signal detection theory and the theory of statistical decision making is known as d'. This is an error measure. The subject's probability of correctly identifying a signal (known as his "hit rate" = 1 - probability of a missed signal) and his probability of responding incorrectly (known as a "false alarm" = responding when no signal was present) are used to calculate d'. The use of this measure does not depend upon the verification of signal detection theory or the theory of statistical decision making. It is merely a means of transforming two types of error scores (false alarms and missed signals) into a single score for each subject. The following paragraph relates the method of computation for d'. The reader who is interested in the derivation of d' and its theoretical importance is referred to Appendix D.

The value of d' for a particular subject is calculated using his hit rate and false alarm rate. The hit rate is the probability of a correct response given a signal was presented, and the false alarm rate is the probability of an incorrect response given no signal was presented. Given these two numbers, d' is calculated using the Gaussian (normal) probability distribution. The Gaussian distribution is tabled in many reference books as a value in standard deviation units (expressed as z) and the corresponding value of the Gaussian distribution (expressed as $F(z)$). To determine d': 1) find the z score that gives the cumulative normal value equal to the subject's hit rate (find z_1, such that $F(z_1)$ = hit rate), 2) find the z score that gives the cumulative normal value equal to the subject's false alarm rate (find z_2, such that $F(z_2)$ = false alarm rate), then $d' = z_1 - z_2$. If the hit rate is high, then z_1 is positive. If the false alarm rate is low, then z_2 is negative, and therefore, d' is large. Thus, the better the subject's overall error performance, the greater is d'.

For example, suppose a subject missed one out of twenty signals on a test run, and made one incorrect response when no signal was presented in twenty "no signal" trials during the same test run (i.e., trials when a non-signal was presented; see Section 2.4.1).

His false alarm rate is 0.05 and his hit rate is 0.95. Then,

$$F(1.65) = 0.95, \text{ hit rate}$$
$$F(-1.65) = 0.05, \text{ false alarm rate}$$
$$\longrightarrow d' = 1.65 - (-1.65) = +3.30$$

This subject would be given a d' score of +3.30 based upon his error scores (false alarm rate and hit rate where hit rate = 1 - probability of a missed signal).

2.7.4.3.2 Analysis of Error Data

The error data for each run of each subject were compiled in terms of false alarms (responses when there was not an appropriate signal) and missed signals (no response when there was a signal). These error data were reduced to d' scores for each run (corresponding to one of the 108 data cells), as outlined in the previous section. The d' score for the one data cell which was not adequately completed was estimated from the other scores, as before. One degree of freedom was sacrificed in assuming that there was no interaction between alcohol, glare, noise/shock/vibration, fatigue, and subjects simultaneously in the error data. The distribution of d' scores was not heavily skewed either positively or negatively. The distribution is shown in Figure 2-11. The scores were distributed over a large range of values. A perfect score (no errors of either type) was assigned a d' value of 5.16 to correspond with the accuracy of the estimates of the error rates. Some subjects were exposed to as many as twenty-three signals and as many as thirty non-signals. The accuracy in estimating their error rates was better than to the nearest 0.05. Thus, the score of $\pm$ 2.58 was chosen (to represent 0.005 accuracy) as the highest possible score. If a subject made no false alarms, for example, $F(-\infty) = 0$, but the subject cannot be credited with a d' of ∞. Therefore, -2.58 was used to correspond to the approximate accuracy of the estimates of the error rates. If the subject had a hit rate of 1.00, then his score would be +2.58, since (F(+2.58) = 0.99506 $\approx$ 1.00 rate. If the subject missed one signal but made no false alarm, then,

$$F(1.65) = 0.95 \text{ hit rate}$$
$$F(-2.58) = 0.00494 \approx 0.00 \text{ false alarm rate } (-2.58 \text{ assumed as best score possible for false alarms})$$
$$\longrightarrow d' = 1.65 - (-2.58) = +4.23 .$$

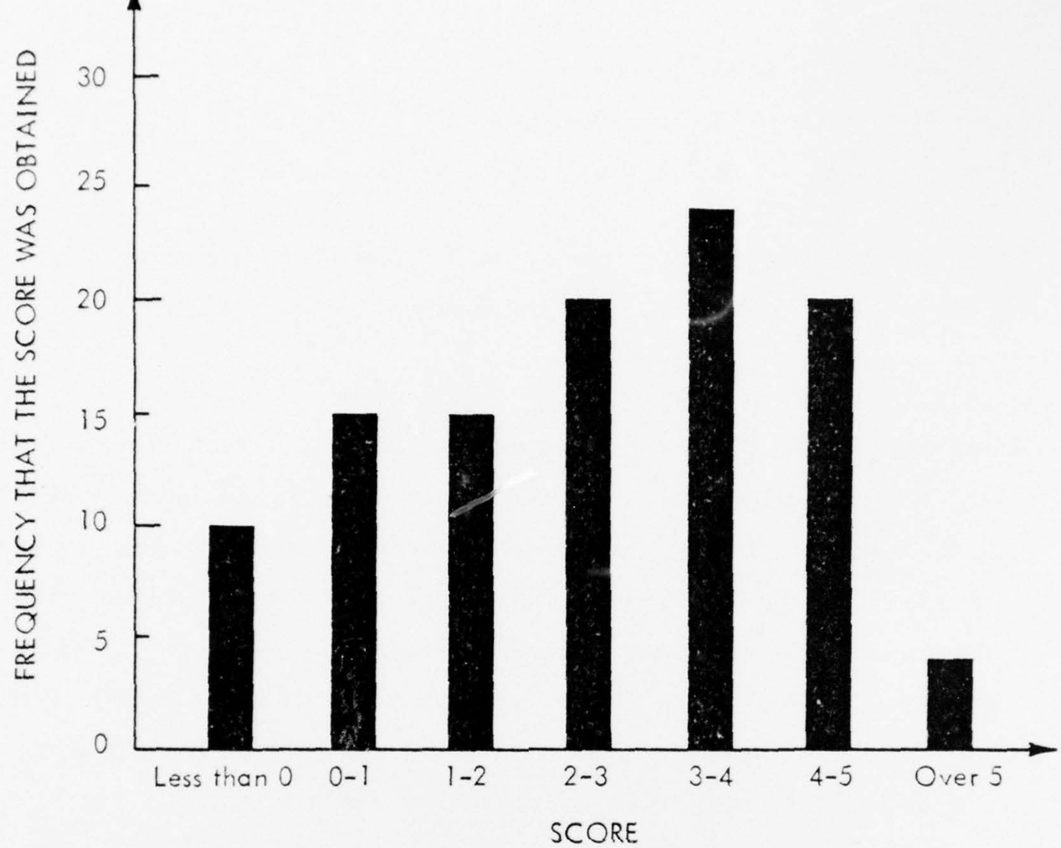


FIGURE 2-11. DISTRIBUTION OF d' SCORES

The results of the analysis of variance on d' scores are shown in Table 2-20. There were 8 - 1 = 7 degrees of freedom in the F x A x N x G x S term and 107 - 1 = 106 degrees of freedom overall because of the necessity to estimate the score from the data cell that was not completed. The lack of a significant F x A x N x G interaction indicates that the assumption (of no interaction) was not contradicted by the data.

Although only two of the F tests proved to be significant (the Fatigue x Alcohol and Glare x Noise interactions), some of these data will be used in Section 2.7.5 to analyze overall effects in terms of speed versus accuracy.

The d' data for the Fatigue x Alcohol interaction are shown in Table 2-21. While there are small differences in the d' scores at 0.00% BAC and 0.05% BAC, the large difference at 0.10% BAC is dramatic. This means the subjects were much more sensitive (more accurate, fewer errors) when rested and drunk than when fatigued and drunk.

TABLE 2-20. VAST-3 ANOVA FOR d' (SENSITIVITY)

Source	d.f.	Sum Sq.	F	P	Significance
S(Subjects)	2	229.2854			
A(Alcohol)	2	1.5254	0.3150	p>.25	Not Significant
AxS	4	9.6856			
G(Glare)	1	0.0428	0.0998	p>.25	Not Significant
GxS	2	0.8575			
AxG	2	1.7023	0.9258	p>.25	Not Significant
GxAxS	4	3.6775			
F(Fatigue)	1	1.7659	2.1450	p>.25	Not Significant
SxF	2	1.6465			
FxA	2	3.8952	30.6950	p<.005	Significant
FxAxS	4	0.2538			
FxG	1	0.0374	0.3105	p>.25	Not Significant
FxGxS	2	0.2409			
FxAxG	2	0.3672	0.5046	p>.25	Not Significant
FxAxGxS	4	1.4554			
N(Noise/Shock/Vib)	2	0.3282	0.0895	p>.25	Not Significant
NxS	4	7.3317			
AxN	4	14.2900	2.2170	.10<p<.25	Not Significant
SxAxN	8	12.8915			
GxN	2	12.8498	7.7537	p<.05	Significant
SxGxN	4	3.3145			
FxN	2	0.6714	0.2084	p>.25	Not Significant
SxFxN	4	6.4432			
NxAxG	4	0.9487	0.4567	p>.25	Not Significant
SxNxAxG	8	4.1552			
FxAxN	4	1.7352	0.4257	p>.25	Not Significant
FxAxNxS	8	8.1524			
NxFxG	2	0.5109	0.4292	p>.25	Not Significant
NxFxGxS	4	2.3803			
FxAxNxG	4	7.0260	1.6265	p>.25	Not Significant
FxAxNxGxS	8-1=7	8.6393			
TOTAL	107-1=106	348.1071			

TABLE 2-21. THE FATIGUE X ALCOHOL INTERACTION IN ERROR DATA

Fatigue Level \ Alcohol Level	0.00% BAC	0.05% BAC	0.10% BAC
Rested	2.32	2.46	2.55
Fatigued	2.37	2.43	1.76

Note: Each datum is the mean d'.

The Glare x Noise/Shock/Vibration interaction data are shown in Table 2-22. As with response times, this interaction is complicated. The tendency was for the subjects to be less sensitive (accurate) when not wearing sunglasses, except under the N_2 condition, when they were more sensitive when wearing sunglasses.

TABLE 2-22. THE GLARE X NOISE/SHOCK/VIBRATION INTERACTION IN ERROR DATA

Glare Level \ Noise Level	N_1 {lo Noise, lo S/V}	N_2 {hi Noise, lo S/V}	N_3 {hi Noise, hi S/V}
With Sunglasses	2.60	1.73	2.55
Without Sunglasses	2.12	2.75	2.15

Note: Each datum is the mean d'.

Error scores were also obtained for the Day 10 test runs. For the subject who wore earmuffs but rode in the rough seat configuration (0.00% BAC rested and then fatigued, with sunglasses, low noise, high shock/vibration), the data in Table 2-23 were obtained.

TABLE 2-23. DAY 10 NOISE/SHOCK/VIBRATION MANIPULATION: ERROR SCORES

	Rested	Fatigued
Mean, all S's (0.00% BAC, low glare, lo noise, lo S/V)	2.79	1.90
Day 10 (0.00% BAC, low glare, lo noise, hi S/V)	3.01	3.55

Note: Each datum is a mean d'.

These data show some slight improvement in sensitivity due to the combination of fatigue and shock/vibration. The data from the Day 10 glare manipulation (when the subject wore sunglasses all day) and the appropriate prior run are shown in Table 2-24.

TABLE 2-24. DAY 10 CUMULATIVE GLARE MANIPULATION: ERROR SCORES

Same subject in both sets of data, 0.00% BAC, high noise, high shock/vibration, fatigued, wearing sunglasses during test.

No sunglasses during fatigue: Cumulative Glare	Sunglasses all day: No Cumulative Glare
3.87	4.05

Note: Data are the d' score obtained.

These data showed very little change in sensitivity due to the Day 10 glare manipulation.

The major impact of the error data is the use of it to account for/or verify the effects witnessed in the response time data. If, for example, the subjects were faster in one condition than another, but they were also less sensitive (accurate), then the response time effect may be due to the subjects changing sensitivity, and not due to the effects of the particular stressors in that condition. This is known as a speed/accuracy trade-off. In Section 2.7.5, the analysis of the data and their meaning will be completed using techniques such as the speed/accuracy tradeoff analysis.

2.7.5 Discussion

In terms of response times, all of the major factors (alcohol, noise/shock/vibration, glare) were found to be at least marginally significant except fatigue. The glare effect was "reversed"; i.e., the subjects performed better without sunglasses than with.

2.7.5.1 Discussion of Learning Effects and Response Data — The learning effects outlined in 2.7.4.2.1 imply improved performance over time. The only factors whose data would have been strongly influenced by learning effects were glare (the subjects always ran without sunglasses as the second of two successive runs) and fatigue (fatigue runs were always the second

set of runs of the day). In general, the overall tendency toward improved performance over time would bias the data somewhat toward the lack of a fatigue effect (some learning making up for some of the effect of fatigue) and toward the lack of a true glare effect (some learning making up for some of the effect of glare).

With respect to glare, three additional considerations were important. Reference 1 gives a brief discussion of the warm-up decrement phenomenon. Subjects typically perform relatively poorly for the first few trials of any run of an experiment, as if they needed to "get warmed up" in order to perform well. Such warm up decrements would be much more likely on the first of two successive runs, and they would contribute to the trend in the observed glare data.

The second additional consideration in the glare data is the nature of the glare manipulation: sunglasses. The sunglasses collected salt spray coming over the light display and the salt and water on the lenses partially obstructed the subject's view of the light display. The frames of the glasses limited peripheral vision.

Thirdly, the on boat glare in VAST was minimal. Almost all the surfaces in the VAST cockpit were flat black or non-reflective. The light display was flat black. Thus, the only on-boat glare sources were the bow rail and the horn. This situation was atypical. Many runabouts have many more glare-producing surfaces (windshields, frames, etc.). It is not surprising that the on-boat glare was not significant in VAST.

Figure 2-12 shows the probability of an error (missed signal) or long response time (greater than 3500 msec) for each area of the display when wearing sunglasses and when not wearing sunglasses. The data show the tendency for errors and long response times to occur more often when peripheral lights were used.

The data in the figure are grouped in sections of seven or eight lights in order to better illustrate trends in the data. When the data are examined light by light, there are different use patterns for different lights (i.e., some lights were used more than others), but the areas of maximum difference between the with sunglasses curve and the without sunglasses curve can then be more accurately determined.

The areas where the curves differ the most are the responses to Lights 11-20 and 31-39. The "with sunglasses" curve shows poorer performance in almost all ranges of the diaplay. Therefore, while limited peripheral vision due to the frames and limited frontal vision due to the salt spray may account for some of the difference, and learning effects may account for some; there is, nonetheless, a clear distinction in performance favoring the "without" sunglasses condition. This may merely reflect the lack of glare-producing surfaces on the VAST boat.

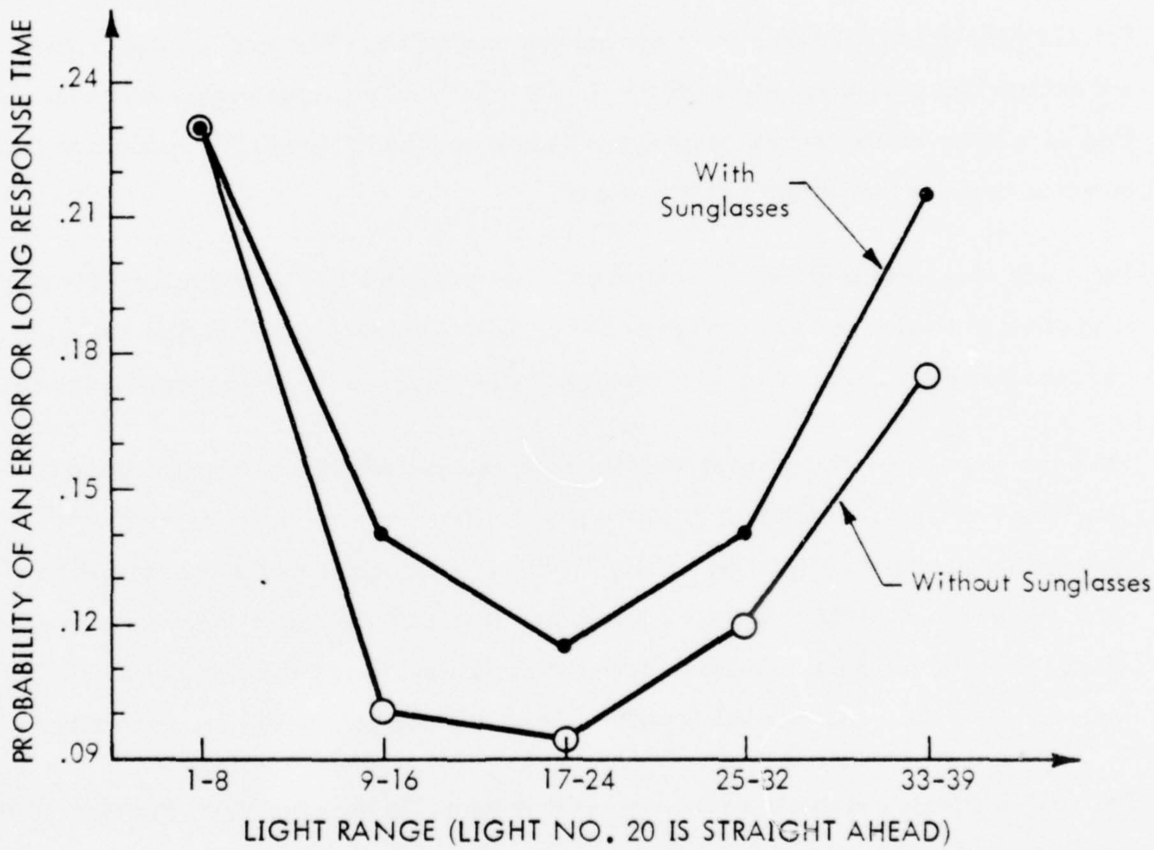


FIGURE 2-12. ERRORS VERSUS LIGHT POSITIONS

2.7.5.2 Speed/Accuracy Tradeoffs — One of the dangers in relying strictly on response time data in any analysis is that changes in mean response times may represent changes in the strategies of the subjects rather than true effects. Thus, error data are always needed. The subject can always improve his performance (lower his response time) somewhat by sacrificing some accuracy. On the other hand, the subject's response time performance may not change, while the true effect appears in his error data.

The error measure used in these analyses is d'. Thus, we must inspect the d' data for each factor in the experiment. If the subjects were faster in one condition than another, but less accurate (lower d'), then the response time effect was due, at least in part, to a tradeoff between speed and accuracy. However, if the subjects were slower with the same level of accuracy, then the response time effect was a "true" effect due to the specific stressor conditions.

The alcohol effect in response times corresponds to d' scores which are not significantly different across alcohol levels. Although the 0.10% BAC data reflected the poorest response times, they also reflected the poorest accuracy. These data tend to support the conclusion that the observed response time effect was a true one.

There was very little difference in the mean d' scores for the two glare groups (with and without sunglasses) although the "without" data, which reflected better response time performance, included a slightly better mean d'. Here again, the response time effect appears to be supported.

The noise/shock/vibration error scores found the best performance to have occurred under N_1 (low noise, low shock/vibration) as in the response time data. The combination of high noise and high shock/vibration (N_3) led to slightly better error scores than the combination of high noise and low shock/vibration (N_2). The effect of shock/vibration at high noise levels that was found in the response time data was statistically significant, while the change in d' was not. Overall, the noise/shock/vibration effect is not contradicted in the error data.

The fatigue effect in response times was virtually zero. In the error data, the mean d' rested was 2.44, while the mean d' fatigued was 2.19. This difference was not statistically significant. The lack of an overall fatigue effect may be due to the previously mentioned learning effects.

The fatigue x alcohol interaction in response times was not significant, but in error scores it was highly significant ($p<.005$). The dramatic effect in the error scores was a tremendous increase in errors when the subjects were both fatigued and drunk. Their response times under those conditions were not different than their times under other conditions. Thus, when drunk and fatigued, the subjects responded just as quickly as under other condtions, but with a much

higher error rate. Therefore, there is evidence that the subjects sacrificed accuracy when fatigued and drunk in order to maintain speed.

In the cases of the fatigue x noise/shock/vibration and glare x fatigue interactions, which were marginally significant in response times, there were no strong trends in the error data to indicate speed accuracy tradeoffs that could account for the response time results.

The glare x noise/shock/vibration interaction was marginally significant in response times and significant in error scores. The interaction data are very similar in the two cases except that the low noise, low shock/vibration, without sunglasses condition led to best performance in response times and poor performance in error scores, indicating a possible speed/accuracy tradeoff for that set of conditions. In general, the description of the interaction that was included in the description of the response time results seems to be accurate: 1) noise has little effect when sunglasses are not worn, while shock/vibration does, and 2) noise and shock/vibration together may have less of an effect when sunglasses are worn than noise alone.

The Day 10 data were supposed to be indicative of two problems that could not be included in the experimental design. One subject ran Day 10 with earmuffs and in the rough seat configuration (0.00% BAC and with sunglasses) to get indicative data concerning the effect of shock and vibration at low noise levels. His response time data tend to indicate that shock and vibration may be important at low noise levels when fatigued. His mean response time when rested was faster under shock and vibration, but it was slower when fatigued. However, the error data show that he was also more accurate under shock and vibration, both when rested and fatigued. Thus, the results are inconclusive.

The second Day 10 problem was that of cumulative glare. One subject wore sunglasses all day on Day 10 to allow a comparison with previous data when subjects wore sunglasses only during certain test runs. The results indicate that cumulative glare may be very important. The subject was both faster and more accurate having worn the sunglasses all day. Of course, more data is needed on this problem to obtain conclusive results.

2.7.5.3 Conclusion: The Meaning of the VAST-3 Data — Table 2-25 shows the significant factors and combinations of factors on each measure. From the table it is clear that any and all factors are important to one degree or another, depending upon the circumstances. This result was not unexpected. Indeed, from the outset of the VAST research endeavor, the interdependence of stressors was hypothesized.

95%

"Stress, then, is not a simple idea, but a complex one. The effects of stress are not static, but dynamic, i.e., they change as the task goes on...Of critical importance then, is the complex nature of stress and stressor effects, and the ability of the individual to maintain his attention upon relevant information in the performance of his tasks." (Reference 1)

TABLE 2-25. SIGNIFICANT VARIABLES IN VAST-3

	Response Times	Error Data
Significant ($p<.05$)	Alcohol	Fatigue x Alcohol Glare x Noise/Shock/Vibration
Marginally Significant ($.05<p<.10$)	Noise/Shock/Vibration Glare Glare x Fatigue Glare x Noise/Shock/Vibration Fatigue x Noise/Shock/Vibration	None

All of the major factors except fatigue (alcohol, glare, noise/shock/vibration) were found to be at least marginally significant in affecting the overall performance (response times and errors) of the subjects. Reasons were proposed for the observed glare effect and lack of fatigue effect, although these proposed arguments may not account for all the observed data.

At first glance, the nature of some of the interactions might appear confusing. For example, why should glare interact with noise? Perhaps the best way to answer questions such as this is to again return to the hypotheses that generated this research. The reason stressors were viewed as complicated and interactive was that the psychological and safety research literatures suggested that the major effects of stressors were on the central processing capabilities of man. The literature concerning alcohol (see Reference 23), for example, strongly suggests that one of the primary effects of alcohol is on information processing and decision making. Early in the development of VAST, a similar conclusion was reached relative to the overall effects of combinations of stressors.

"It is possible that a major component to fatigue is a degradation in information processing, because the light activity and exposure had the same gross effect as the more vigorous physical activity..." (Reference 1)

If the effects of stressors are primarily on the central processing functions of the individual, then it is not fortuitous that stressors such as glare and noise/shock/vibration should interact. The fact that these stressors are processed through different sense modalities does not preclude their interacting once the information from all the senses is processed within the central nervous system.

The VAST-3 experiment was an ambitious undertaking. The computer, data recording system, subjects, experimenters, and other personnel were asked to perform for two solid weeks of dawn to dusk activity. As was mentioned in Section 2.7.4.1.3, the VAST computer and data recording systems functioned well. The weather varied somewhat, but was generally good and warm. Considering the opportunities for severe learning effects, computer breakdown, illness, poor weather, etc., the experiment went remarkably well. The absence of any significant higher order interactions (more than two factors) speaks very well for the apparatus, the experimental design, and the people involved. No confounding interactions were detected.

Of course, it must be remembered that VAST is not (nor was it intended to be) a precise simulation of boating activity. It is a visual alertness task that is performed on a boat under real-world conditions. The results from VAST are indicative of the kinds of effects that might be present in the boating population due to stressors. VAST-3 has shown that alcohol and noise/shock/vibration are significant (at least marginally) stressors. Glare is a problem that probably requires more analysis (see succeeding sections). Fatigue was not significant in VAST-3 by itself (although some reasons for this were found), but it was significant in combination with other stressors, such as alcohol.

Several nagging questions remain. What have we accomplished with VAST so far? What have we learned? What does it mean? How can we use what we have discovered? Where do we go from here? These are important questions. They will be dealt with in the next section, since these issues relate to all of the VAST experiments.

2.8 Overall Results And Implications of VAST

Many factors and combinations of factors have been found to be statistically significant in terms of response times and/or errors in the three VAST experiments. Of the stressors that were studied, alcohol and fatigue have been shown to have repeatedly significant effects on performance on VAST (individually and in combination with particular levels of other stressors). It is argued below that the magnitudes of these effects have been underestimated by VAST, and that several sources of variation in the experiments preclude attaching meaningful "real time" data to the overall effects across all three experiments.

It should be noted that there is a difference between statistical significance and importance. While there may be a statistically reliable difference in the average distance the ball flies in making a 30 yd (27.4 m) field goal by two different place kickers in football, the difference is probably not important since the end result of any 30 yd (27.4 m) field goal is the same. In VAST-1, the average difference between rested and fatigued subjects on the VAST task was almost two seconds. The issue now is, is the approximate two second difference from VAST-1 important?...or any difference in VAST?

The two second difference in VAST-I due to fatigue may not represent the true magnitude of the stressors effect in "real time." The VAST task is a quick response task. All the subject must do is decide if he has seen an appropriate stimulus, and if so, push a button. The stimuli are complicated, but simpler than the real stimuli of boats. With the lights, there was no depth perception, no glare on the target, no visual obstructions, etc. The response was also easier. It's certainly much easier to push a button than to decide upon a maneuver to execute and then do it. VAST is also a visual task, and does not measure non-visual effects. In VAST, the subject knows what to expect and exactly how to respond. In the real world, the operator must detect a situation, decide how to respond to it, and execute the proper response. Thus, the measured two second difference underestimates the true difference in real time. In addition, a boat traveling 30 mph (48 kph) will travel 44 ft (13.3 m) per second. A time difference of two seconds due to fatigue (which, from the previous discussion, is a conservative estimate) would mean the boat would travel an additional 88 ft (26.7 m) before the operator could react. How many accidents might have been prevented or avoided if the operator had reacted 88 ft (27 m) sooner? Obviously, this kind of a difference is important.

Fatigue results in VAST-2 and VAST-3 were not as dramatic in terms of measured time effects as in VAST-1. At this point, the discussion from Section 2.6 should be recalled. Although the discussion above relates to the importance of a two second delay in responding in boating, it also comments on the fact that the VAST experiments do not measure stressor effects in "real time." Similarly, the VAST measurements do not correlate well across experiments in terms of their magnitude. The fatigue effect in VAST-2 was approximately a 200 millisecond difference in response times (fatigued versus rested), while the fatigue effect in VAST-1 was about 2000 milliseconds. Why are the magnitudes of these two statistically significant effects different? There are many possible reasons: the subjects were different, the extent of training was different, the fatigue scenarios were not identical (recall, there were two different scenarios in VAST-1), weather (wind, heat, clouds, humidity) conditions were different, water conditions were different, etc. The fatigue results of VAST-2 were of a greater statistical significance than those of VAST-1 (see Tables 2-3, 2-4, and 2-5), even though the actual magnitude of the observed difference was less. The critical point of these paragraphs is that the VAST results (in terms of delays in responses introduced by fatigue or any other stressor) underestimate the delays in "real time." In one instance (VAST-1) the delays on the VAST test were long enough that they would be important in the real world even if they did not underestimate the real world effects. For other differences in VAST, the importance of the result depends upon one's perception of the difference between the VAST task and real world boating activities were the coordination between eye movements, decisions, and skill (execution of a response) might be important. If the argument that VAST greatly underestimates the true magnitude of response times is accepted, then even small response time effects (such as the 200 msec effect due to fatigue in VAST-2) may be termed important, and the two second fatigue effect from VAST-1 is seen to be more representative of the true effect than the 200 msec effect from VAST-2. In each experiment, the effects have been evaluated only under the conditions of that experiment for the reasons outlined above. The significance of repeated tests can be <u>compared</u> across experiments (such as fatigue in VAST-1 as opposed to VAST-2), but the magnitudes of the effects cannot be <u>combined</u> for the reasons outlined above, and comparisons of these magnitudes are not meaningful without reflecting upon the differences between the experiments.

The trials in experimental runs that contributed greatly to the observed differences in the experiments are important. These were the trials where the subject failed to respond to a signal. The subjects in VAST-1 missed ten signals in the afternoon and only one in the morning. Thus, the important difference might be the tendency to miss signals (perhaps "miss" another boat) under fatigue, or another stressor. This difference was a major contributor to the observed difference in response times for fatigued versus rested subjects in VAST-1. A missed signal is not just a delay in the response but no response at all. The fatigue or stressor effect may be one reason why so many boaters say, after a collision, "I never saw the other boat," or, "He didn't have his lights on." The effect of causing the boater to miss signals, or other boats on the water is very important indeed.

The performance of the computer in VAST-3 allowed the error data to be analyzed in even greater detail. While missed signals are obviously important, inappropriate responses (false alarms) can lead to accidents also.

To summarize this discussion, three important facts which should be remembered when evaluating VAST (or any such "stress tester") are: 1) at best, it is only a simulation of boating activity, and not "the real thing," so results must be analyzed in terms of their relationship to true boating activities; 2) VAST is real world oriented, so as many real world aspects as possible were included (short of having an actual collision), and these results must be more highly correlated with the "true" boating stressor effects than any laboratory tests; and 3) since VAST is a simulation which probably leads to shorter reaction times than the "real world," absolute response time differences and error score differences in VAST do not reflect true stressor effects in boating, only in VAST. Indeed, point No. 3 may be the most important. VAST may underestimate (from the logic presented above) the true nature and magnitude of stressor effects. Due to these arguments, and the magnitude of some of the effects measured with VAST, it is not unreasonable to consider all <u>statistically significant</u> effects in VAST as <u>important</u>. Indeed, previous research in the area of stressors has produced "significant" results on the order of 250 milliseconds or less; VAST results are typically at least this magnitude (VAST-2) and as much as eight times larger (VAST-1).

Although it will be argued later that all stressors are important to one degree or another on VAST, the following paragraphs will outline the significant findings on each major stressor throughout the experiments.

Fatigue was found to be significant in VAST-1 and VAST-2. In VAST-1 two types of fatigue were tested and each led to significant degradation of performance. In VAST-2, under different weather, subjects, and somewhat different activities, fatigue was again significant.

Fatigue was not significant as an individual factor in VAST-3, but a reason (learning) was proposed as an explanation for at least part of the data. Also, in VAST-3, fatigue was found to be significant at certain alcohol levels (fatigue x alcohol interaction in errors) and marginally significant in some glare conditions (glare x fatigue interaction in response times). Thus, overall, fatigue has been subjected to the greatest study in VAST, and has influenced data (both response times and errors) significantly in all three experiments. The fact that fatigue in VAST is defined merely as exposure to the elements and light exercise for three hours adds to the importance of these findings. VAST indicates that fatigue is important at levels which may be common to almost all boaters in their normal activities.

Alcohol was found to be an important stressor also. In VAST-2 and VAST-3 it led to significant decrements in performance. Alcohol effects were not found to interact significantly with other stressors except in VAST-3, where the combination of alcohol and fatigue was found to lead to very poor performance in terms of errors.

Noise and shock/vibration were marginally significant in VAST-3. They led to orderly (overall) degradations in response time performance and interacted with glare and fatigue (individually). It appears that noise and shock/vibration effects are difficult to predict because of the complicated nature of some of their interactions. Thus, while it appears that these variables may be the easiest for the USCG to control via regulation, they may be the most difficult to define in terms of their interactive effects.

In VAST-2, the sizes of the fatigue effect and the effect of alcohol (approximately 0.10% BAC) were approximately the same (about 200 msec degradation in response time due to fatigue when sober, about 300 msec degradation due to alcohol when rested). In VAST-3, the average

degradation due to 0.10% BAC was again approximately 300 msec, but the effect of 0.05% BAC was a 140 msec improvement in response times, on the average. Thus, there is evidence for the conclusion that 0.10% BAC leads to a significant degradation which was approximately equal to the fatigue effect of the three-hour scenario in the VAST-2 experiment. However, since subjects, location, weather, etc., were variables across experiments, it is not possible to use these data to generate a scale of stress in general which could be used to compare effects. Such comparisons have been made only within individual experiments. The "alcohol as a scale" concept suffers because of the significant interactions in VAST-3 as well. Because of the interactions among several variables (alcohol and fatigue in particular), it is not possible to set meaningful individual lower limits of exposure for some variables such that exceeding those limits always leads to significant degradations in performance while less exposure does not. Since particular combinations of variables lead to greater performance degradations than others, and since boaters are usually exposed to several stressors simultaneously, it is not possible to create meaningful scales for individual stressors except to the extent of identifying (where possible) excessive levels which always lead to degradation. These upper limits may be so high for some variables as to be meaningless. With the results available from VAST so far, an alcohol level of 0.10% BAC appears to always result in a performance degradation in response times. This result is meaningful since the 0.10% BAC level is attained by many people. Other excessive levels may not be easily identified because of interactions and individual differences (discussed below). For example, is 0.075% BAC excessive? Such cases would preclude real world standard development on a variable by variable basis. However, excessive levels can be identified where possible and joined with variable combinations which are known to lead to degradations (such as 0.10% BAC plus fatigue leading to high error rates) to form a stressor profile. Such a profile might generate an index of stress which would reflect a weighting of various exposures to stressors and stressor combinations. The development of such an index is well beyond the scope of the VAST efforts to date, but results from VAST-1, VAST-2, and VAST-3 indicate that such an integrative approach to stressor scaling and measurement is appropriate.

Glare is one variable which has only been studied in one aspect: its temporary and immediate effects. Cumulative glare has not been studied except to the extent that it was indicated as

a potential problem by some VAST-3 data. The glare effect that was observed in VAST-3 as marginally significant favored the "high glare" condition. This could have been due to learning, or the lack of on-boat glare, or other effects discussed previously. However, glare did interact significantly with noise (and fatigue to a lesser extent). Thus, glare requires further study, especially in terms of its cumulative effects.

Individual differences cannot be ignored. A large component of the sum of squares in the ANOVA for VAST-3 was the subjects sum of squares. Examination of the data from VAST-1 and VAST-2 also indicates variation in the performances of different subjects. Therefore, while the stressor effects outlined above were for all the data (pooled across subjects), stressors will obviously affect different people to differing degrees; some will be affected to a greater extent, and some less.

Through the three VAST experiments several goals have been accomplished. First, and foremost among these, we have learned that stressors in boating do lead to significant and important performance degradations. Second, a stressor measurement tool has been developed and refined which allows the manipulation of stressors and is sensitive to their effects on boaters. Third, we have at least begun to break down the boating environment into its component stressors and to analyze their individual and combined effects. Finally, the overall view of the role of stressors in boating is becoming clear. Stressors lead to performance decrements. Stressor effects appear to be greatest on central processing in the boatman. Thus, stressors are often not detected as a problem by the boater, while they may be influencing his every action and decision. In VAST we have studied stressor effects only on vision. Obviously, stressors affect other senses and abilities as well. These aspects of stressors, when combined with human factors problems in boat design and cockpits, plus additional boater-induced problems (overloading, instability, etc.), demonstrate the likely situation of a boater whose world is full of pitfalls and dangers. The errors or delays introduced by stressors may be enough to cause an accident, or provide the catalyst for another cause.

The tendency for stressors to affect central processing, and the fact that all stressors appear to have significant effects (at least in some circumstances) means that they cannot be regarded lightly. So, what do we do about them? Since it is difficult to regulate many stressors (such as the sun, or alcohol, etc.), education appears to be the key to reducing their effects. The

public needs to be made aware of stressors, their effects, their significance, and the fact that their effects are often not detectable until it is too late. Some regulatory steps may be taken (such as reducing glare-producing lights and surfaces, reducing noise, etc.) which could provide some relief from stressor effects.

The nature of these programs was not to be determined by VAST, although the direction seems clear: reduce stressor levels whenever and wherever possible. The major stressor effects were due to fatigue and alcohol in the VAST studies, and education appears to be the only effective means available to handle these particular stressors at present.

3.0 PROBLEM DEFINITION

3.1 Introduction

Phase II of the collision research effort extended the work of Phase I which was devoted to problem definition and identifying the causes of collisions. The 1975 research concentrated on the following areas:

- Experimentation, using the VAST apparatus to measure the effects of stressors and boat operators' performance.
- Analysis of a sample of collision reports to determine collision causes, the presence of stressors, etc.
- Statistical analyses of the data obtained.

The VAST experiments were discussed in Section 2.0. The results of the collision report analysis and the associated statistical tests are described in this section and in Section 4.2. Information on the following topics is included in this section.

- Availability of stressor and cause information in different type reports.
- Comparison of causes coded from BAR or MIO reports with that from in-depth reports.
- Relative frequencies of presence of stressors and certain other human factors.
- Absolute and relative frequencies of collision causes in analyzed sample.
- Comparison of causes in fatal and non-fatal collisions.
- Comparison of collision causes by boat length.
- Examination of the relationship of collision causes to malfunctions.
- Examination of operator-related collision causes.
- Analysis of the frequencies of occurrence of certain combinations of stressors and human factors.
- Analysis of relationships between collision causes and stressors found important in VAST experimentation.

Section 4.2 includes additional information on visibility-related causes, including daytime/nighttime cause comparisons.

3.2 The Data Base

Present accident coding methods were not designed to select stressor-related causes from the accident data. Therefore, a new system of cause coding was devised. The new system was discussed in Phase I, Volume I (Reference 1), of the collision research effort and was revised during Phase II of the effort.

The data organization system was based on three forms. Basic data on the boat and accident was coded into Wyle's WATS Data Update Form (Figure 3-1) which was developed for obtaining additional information through call-back on accidents initially reported over the Coast Guard WATS reporting line. Primary causes were determined through use of a Collision Cause Coding Tree (Figure 3-2).

The decision tree forces the accident analyst through a more logical causal determination process than does the present cause list system. In general, the more one knows about a particular collision, the further down the tree one can travel. Each time the analyst makes a decision and travels further along the tree, a useful piece of information is gained. For instance, if Block 235 (Glare From Sources Not on This Boat) is coded, one also knows that the other boat or object probably wasn't recognizable, the operator didn't see the boat or object, he didn't try to take an avoidance action and his boat was underway. Appendix A contains definitions of the cause block titles in the tree.

Some types of data including stressor and human engineering data could not be efficiently handled using the decision tree approach. This was primarily due to the likelihood of more than one operator stressor or human engineering problem being present and the likelihood that the data source for an accident would contain little, if any, information on these factors, making more than simple yes/no/unknown decisions impossible. A human factors questionnaire (Figure 3-3) was therefore developed for use in coding data on operator stressors, human engineering problems and additional questions not covered on the other two forms.

Name ______________

DATA UPDATE FORM

Date ______________

COLUMN	INFORMATION		NO. OF INTERGERS ALLOWED
01-06	Accident Number	______	6
07	Code Level	______	1
08-09	Month	______	2
10-11	Day	______	2
12-13	Year	______	2
14	Day of Week	______	1
15-17	Time of Day	______	3
18-20	Accident Type	______	3
21-22	State	______	2
23-24	District	______	2
25	Operator's Experience	______	1
26-27	Operator's Age	______	2
28	Operator's Formal Instruction	______	1
29	Type Boat	______	1
30	Hull Material	______	1
31-32	Length (ft)	______	2
33-35	Beam (in.)	______	3
36-37	Boat Age (years)	______	2
38	Propulsion System	______	1
39-41	Horsepower	______	3
42	Hull Type	______	1
43-45	People Capacity (10's lb)	______	3
46-48	Hull Weight (100's lb)	______	3
49-51	Maximum Weight (100's lb)	______	3
52-54	Horsepower Capacity	______	3
55-56	People On Board	______	2
57-58	PFDs On Board	______	2
59-60	PFDs Worn	______	2
61-62	Fatalities	______	2
63-64	Injuries	______	2
65-66	Duration of Operation	______	2
67-68	Operation at Time of Accident	______	2
69	Number of Boats Involved	______	1
70-72	Damage ($ 100's)	______	3
73-74	Air Temperature (Farenheit)	______	2
75-76	Water Temperature (Farenheit)	______	2
77-78	Wave Height (in.)	______	2
01	Wind	______	1
02	Weather	______	1
03	Visibility	______	1
04	Water Type	______	1
05-10	Cause Code	______	6
11	Operator's Sex	______	1
01-240	Narrative } Use Back of Form	______	240
01-80	Comment } Use Back of Form	______	80

FIGURE 3-1. WATS DATA UPDATE FORM

95%

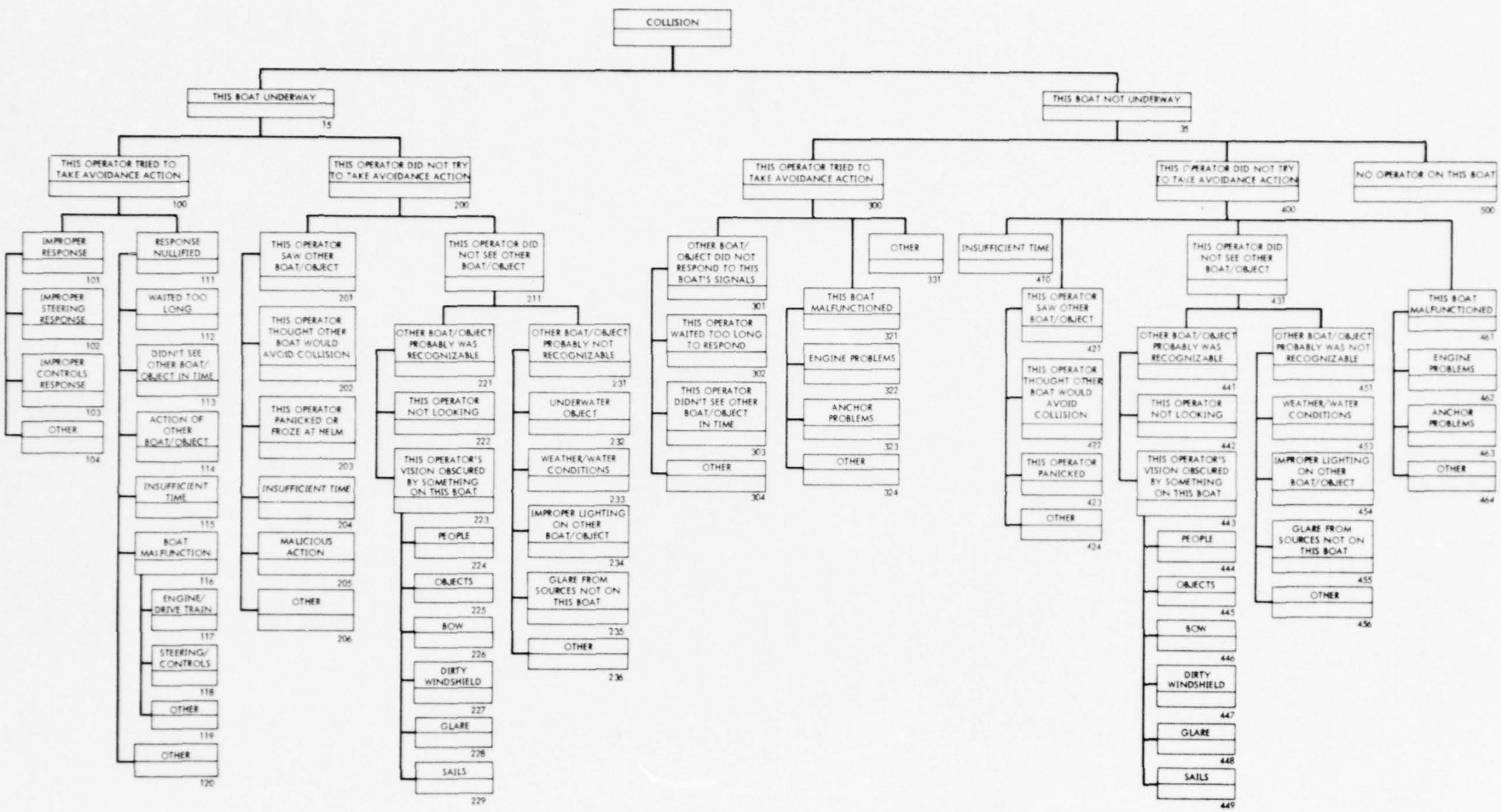


FIGURE 3-2. COLLISION CAUSE CODING TREE

No.	Item	Yes	No	Unknown	N/A
1.	How long had this operator been on water? ________ Hrs	X	X		
2.	This operator was: Sober				
3.	Had been drinking				
4.	Was legally drunk				
5.	This operator subjected to high amount of: Shock/Vibration				
6.	Noise				
7.	Glare				
8.	Human engineering problem with control station or controls				
9.	Just prior to the collision, this operator: Was in proper position				
10.	Was looking away				
11.	Was at the helm				
12.	Made a navigational error				
13.	Was operating in a reckless or malicious manner				
14.	Signalled other vessel				
15.	If this collision occurred at night, were the lights legal on this boat?				
16.	Was this boat priviledged?				
17.	Before the collision, this boat was: Proceeding too fast for conditions				
18.	Out of control				
19.	In hazardous waters				

FIGURE 3-3. HUMAN FACTORS QUESTIONNAIRE

The data base consisted of a total of sixty-one two-boat collisions and forty-four single boat collisions, including twenty-seven collisions with fixed objects, eight collisions with floating objects, and nine groundings, for a total of 166 boats involved. Collisions representing fifty boats were randomly chosen from each of the 1969 and 1973 Coast Guard accident files. The sample was also evenly divided between non-fatal accidents having only Boating Accident Reports (BARs) as source documents and fatal accidents which included Marine Investigation Officer (MIO) reports and (usually) BARs.

The remaining forty-four accidents representing sixty-six boats were divided among the Wyle 1974 in-depth investigations, 1975 in-depth investigations, and 1975 telephone interviews. The following chart details the number and kind of collisions from each source.

Number of:	Boats	Collisions	Two Boat Collisions	Collisions W/ Fixed Objects	Collisions W/ Floating Objects	Groundings
1969 BAR's	25	16	9	5	2	0
1969 MIO	25	15	10	4	1	0
1973 BAR's	25	15	10	4	1	0
1973 MIO	25	15	10	2	2	1
1974 In-Depth	12	6	6	0	0	0
1975 In-Depth	15	10	5	4	0	1
1975 Telephone Interviews	39	28	11	0	2	5
TOTALS	166	105	61	29	8	7

The decision to choose a relatively large proportion of MIO reports, which are only written for fatal accidents, was governed by the knowledge that BARs would, in most instances, furnish insufficient information to yield human factors data. As a consequence of this decision, the data base was heavily biased towards fatalities; much more so than CG-357 statistics. The following table compares the percents of sampled collisions which were fatal with the corresponding percents derived from 1969-74 CG-357 statistics.

	Percent of Collisions Which Were Fatal	
	Sampled Data	1969-74 CG-357 Statistics
Groundings	22.2	5.0
Collision With Another Vessel	41.0	3.6
Collision With Fixed Object	18.5	11.2
Striking Floating Object	37.5	11.1
OVERALL	33.3	6.0

Because these percents were different in the sampled data from CG-357 statistics, a decision had to be made as to whether or not the sampled data should be weighted so as to reflect the CG-357 percents. After consideration, it was decided not to weight the sampled data for two reasons. First, such weighting would greatly increase the relative size of the already large number of unknown data points, as the weighting would favor non-fatal accidents for which less data was available (no MIO report). Second, as the primary purpose of the boating safety effort is to save lives, it is most important to reduce the number of fatal collisions. Thus, it was felt that data biased towards fatal collisions would better serve this goal.

Although the sample was biased towards fatal collisions, little bias was present in the selection process with respect to the type of collision. The relative proportions of collision types in the sample very closely reflected the proportions in CG-357 statistics, as the following table shows, and thus no weighting was needed to adjust the sample for collision type.

	Percent of Collisions	
	Sampled Data	1969-74 CG-357 Statistics
Groundings	8.6	11.1
Collision With Another Vessel	58.1	58.9
Collision With Fixed Object	25.7	21.6
Striking Floating Object	7.6	8.3

3.3 Coding Technique

Three qualified coders were chosen to code each collision. A separate coding tree and questionnaire was completed by each of the three coders for each of the 166 boats involved. Their answers were compared and the yes/no discrepancies on the questionnaire were noted and were worked out among them. Yes/Unknown and no/unknown discrepancies were not worked out but were recoded on the basis of the solution which the two coders chose. The chart following illustrates how the system worked.

Two Coders Chose	One Coder Chose	Code
* Yes	No	Unknown
* No	Yes	Unknown
Yes	Unknown	Yes
No	Unknown	No
Unknown	Yes	Unknown
Unknown	No	Unknown

* Note: These were only coded when the disagreement could not be worked out, which occurred in very few cases.

Very few discrepancies occurred among coders when using the coding tree. Those discrepancies that did occur were ones where coders coded different causes within the same branch of the tree. For instance, two coders might have chosen Number 112 (Waited Too Long) and one coder may have chosen 113 (Didn't See Other Boat/Object in Time). The definitions of these causes are quite similar (Appendix A). In such cases, the final cause code attached to that boat was the one which two of the three coders decided upon.

3.4 Results of the Data Analysis — General

We now examine some of the more general results of the data analysis effort. In later sections we will examine in more detail the significance of the data results as applied to specific areas.

In order to determine the usefulness of the various data sources (BARs, MIO reports, etc.) in obtaining human factor information, the percent of "unknowns" coded for each question on the human factors questionnaire was calculated. The results are shown in Table 3-1. In general, only the 1975 in-depth reports furnished a substantial amount of human factors information. Basically, this is because it was mainly in the 1975 in-depth accident investigations that human factors problems were particularly sought.

TABLE 3-1. PERCENT OF "UNKNOWNS" CODED ON HUMAN FACTORS QUESTIONNAIRE

Question	Percent of Answers (boats) Coded "Unknown"					
	Overall	BAR's	MIO Reports	Telephone Interviews	1974 In-depth Reports	1975 In-depth Reports
1. How long	77	92	62	92	67	27
2. Sober	85	94	88	92	83	27
3. Had been drinking	84	92	86	92	83	20
4. Legally drunk	91	94	94	97	100	47
5. Shock/Vibration	86	98	94	97	83	7
6. Noise	85	96	94	90	83	7
7. Glare	83	94	86	90	67	27
8. H. E. problem	84	92	92	90	50	40
9. Proper position	78	86	82	79	67	27
10. Looking away	65	74	72	72	33	20
11. At helm	29	40	22	41	8	0
12. Navigational error	20	12	22	38	0	7
13. Reckless/Malicious	33	38	42	41	0	7
14. Signalled	13	24	6	15	8	0
15. Lights legal	17	18	26	21	0	13
16. Privileged	42	82	24	31	33	27
17. Speeding	40	52	40	46	8	13
18. Out of control	39	44	50	41	0	7
19. Hazardous waters	40	52	34	56	0	7

Table 3-2 shows the relative proportions of the "yes" and "no" answers on the human factors questionnaire. The "yes" percents were calculated by dividing the number of "yes" answers by the total number of "yes" and "no" answers to each question. In addition to the information provided in this table, answers to question 15 also yielded the percents of day and night collisions: accidents coded "not applicable" were daytime; all others were nighttime. Sixty-five percent of the sample collisions occurred during the day while 35% occurred at night.

The information in Table 3-2 must be treated carefully, with the realization that because of the large percentages of unknown results for some questions, some of these percents could be grossly biased. This could occur, for instance, if information relevant to a particular question is only reported when the factor involved is obviously present, as probably would be the case for alcohol consumption or speeding. Because there is no data on the general boating population, this data could not be compared to data from non-accident situations. However, it is used later in this report with other data obtained in our research.

Figure 3-4 summarizes the results of the collision cause analysis. In each block of the tree, the number of boats coded with that cause has been entered. As described before, for any coded cause, every branch point preceeding that cause is also applicable. For instance, all instances of Cause 118 (Steering/Controls) is also an instance of Causes 116, 111, 100, and 15. Figure 3-4 illustrates only the one cause coded for each boat. Figure 3-5 indicates cumulative totals at each branch point. Thus, the total at Block 111 (Response Nullified) includes the total of all boats coded 111 through 120. Figures 3-6 and 3-7 indicate the percents corresponding to the totals in Figures 3-4 and 3-5, respectively. All percents were calculated from the original data to minimize rounding errors. In all figures, no number is entered into a block if there were no instances of that cause in the collision sample. Of the 166 boats in the sample, five could not be identified even as to whether or not they were underway.

In addition to comparing the amount of human factors information available from the various types of accident reports used, a comparison was made between the collision causes determined from analysis of BAR and MIO reports and the causes determined from in-depth reports. Figure 3-8 shows the distributions of causes from the two report classifications and Figure 3-9 contains the

TABLE 3-2. PERCENTAGE RESULTS OF HUMAN FACTORS ANALYSIS *

		Yes	No
1.	How long had this operator been on the water? ______ Hrs	—	—
2.	This operator was: Sober	44	56
3.	Had been drinking	56	44
4.	Was legally drunk	13	87
5.	Prior to the collision, this operator was subjected to a high amount or prolonged exposure to: Shock/Vibration	65	35
6.	Noise	68	32
7.	Glare	86	14
8.	Human engineering problem with control station or controls	90	10
9.	Just prior to the collision, this operator: Was in proper position	52	48
10.	Was looking away	45	55
11.	Was at the helm	92	8
12.	Made a navigational error	34	66
13.	Was operating in a reckless or malicious manner	63	37
14.	Signalled other vessel	5	95
15.	If this collision occurred at night, were the lights legal on this boat?	50	50
16.	Was this boat priviledged?	41	59
17.	Before the collision, this boat was: Proceeding too fast for conditions	43	57
18.	Out of control	30	70
19.	In hazardous waters	16	84

* Percents as a function of known answers excluding "not applicable" answers.

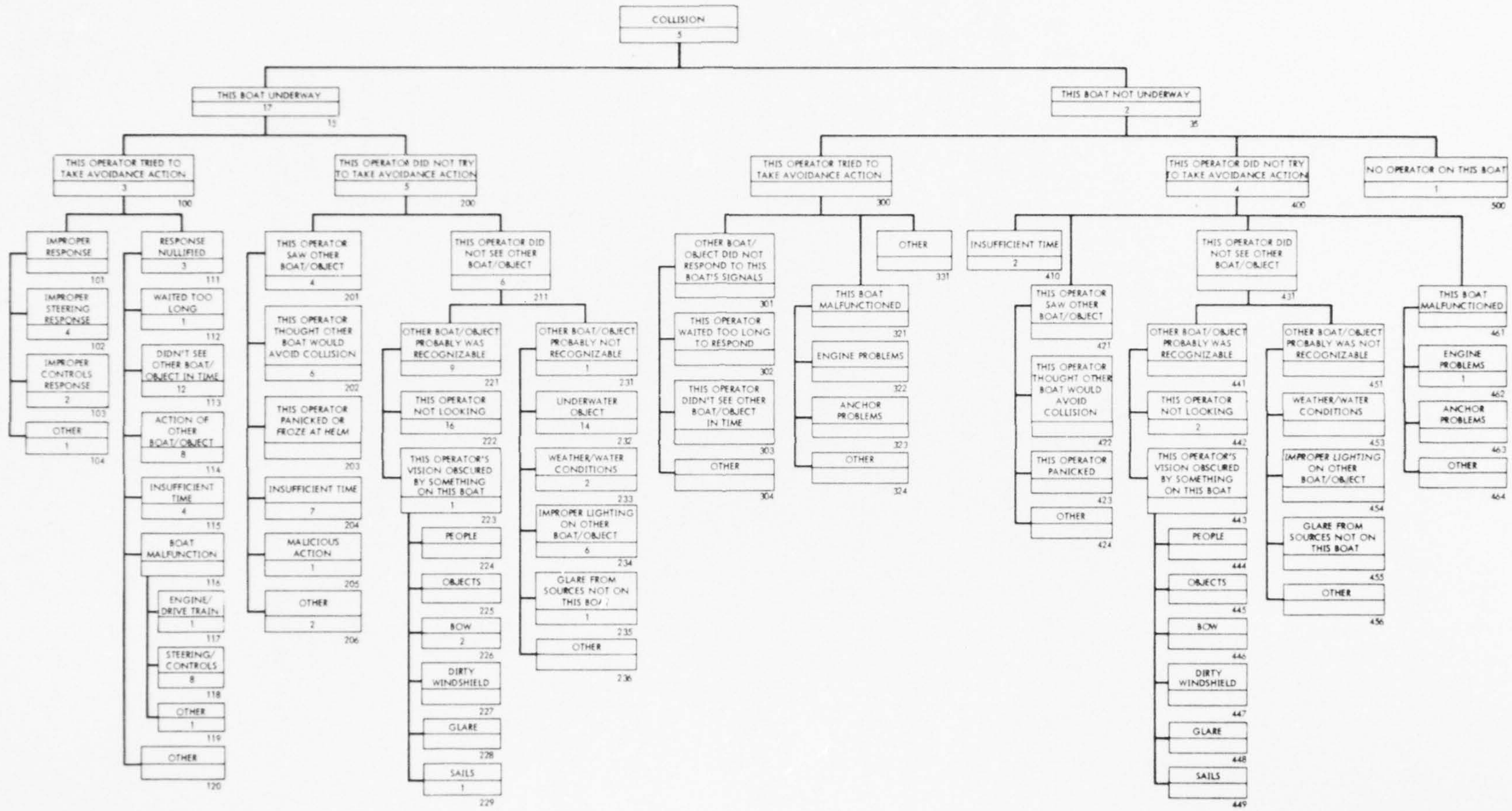


FIGURE 3-4. CAUSES IN ALL COLLISIONS

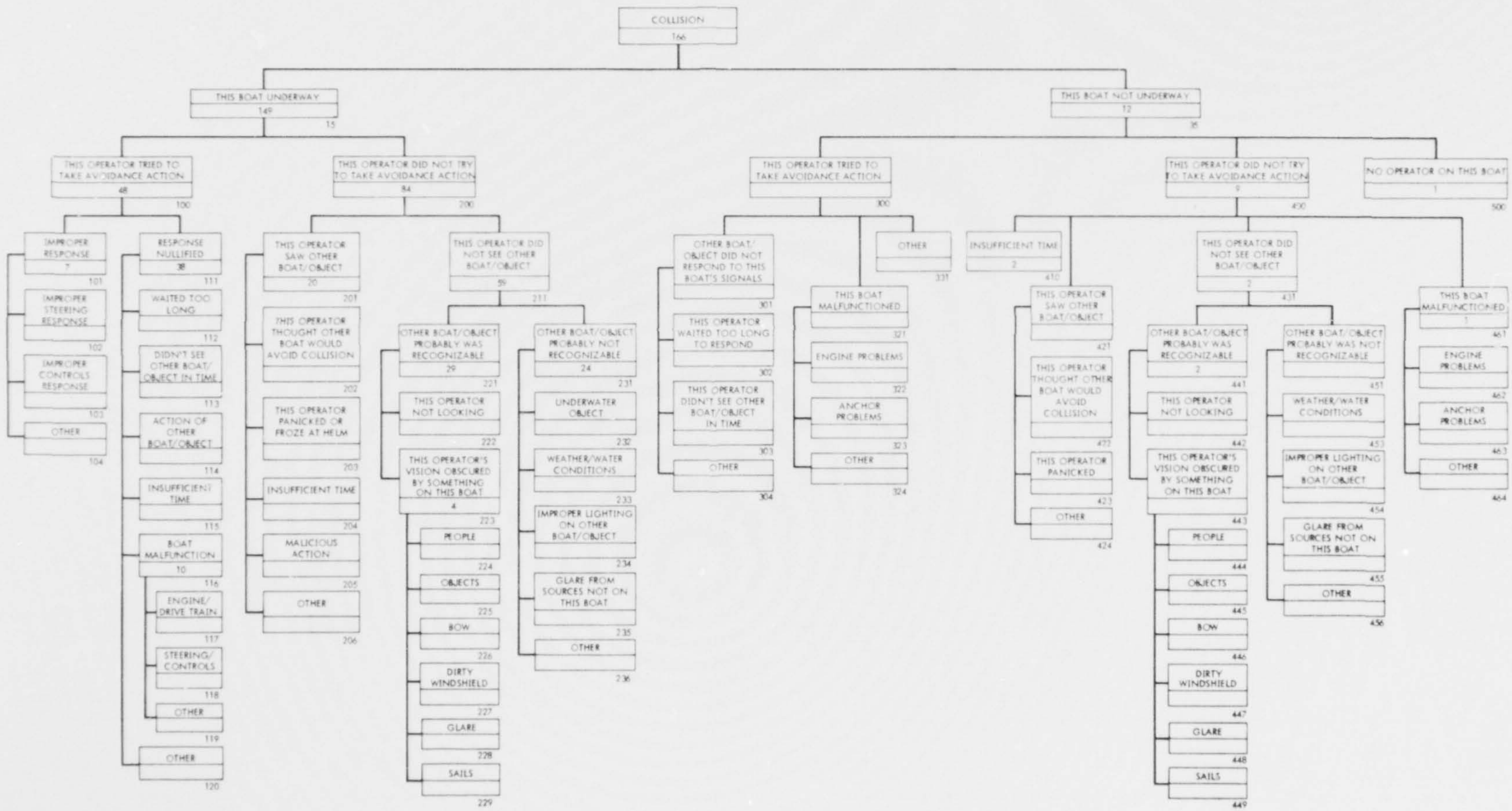


FIGURE 3-5. CUMULATIVE CAUSES IN ALL COLLISIONS

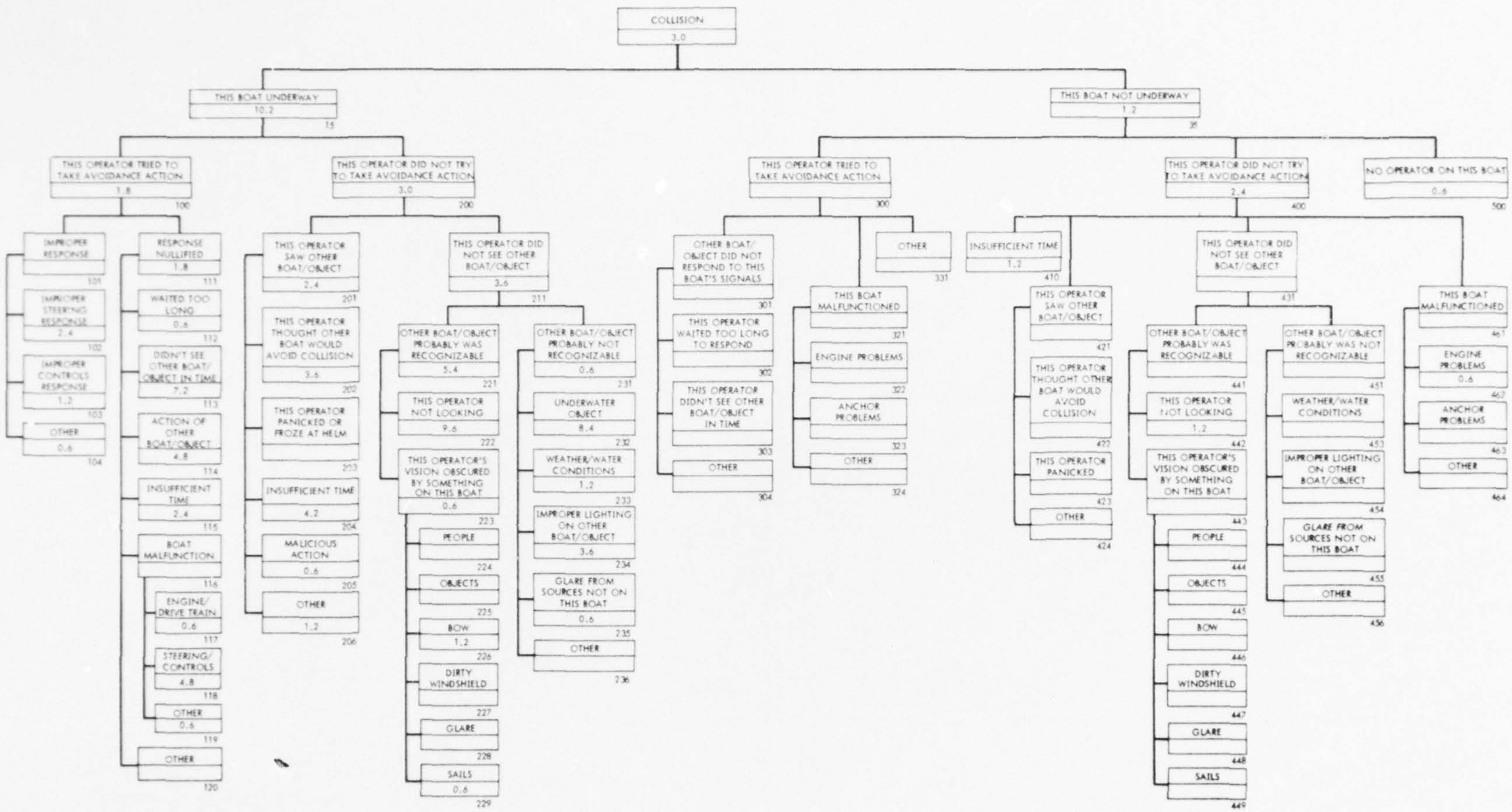


FIGURE 3-6. CAUSE PERCENTAGES IN ALL COLLISIONS

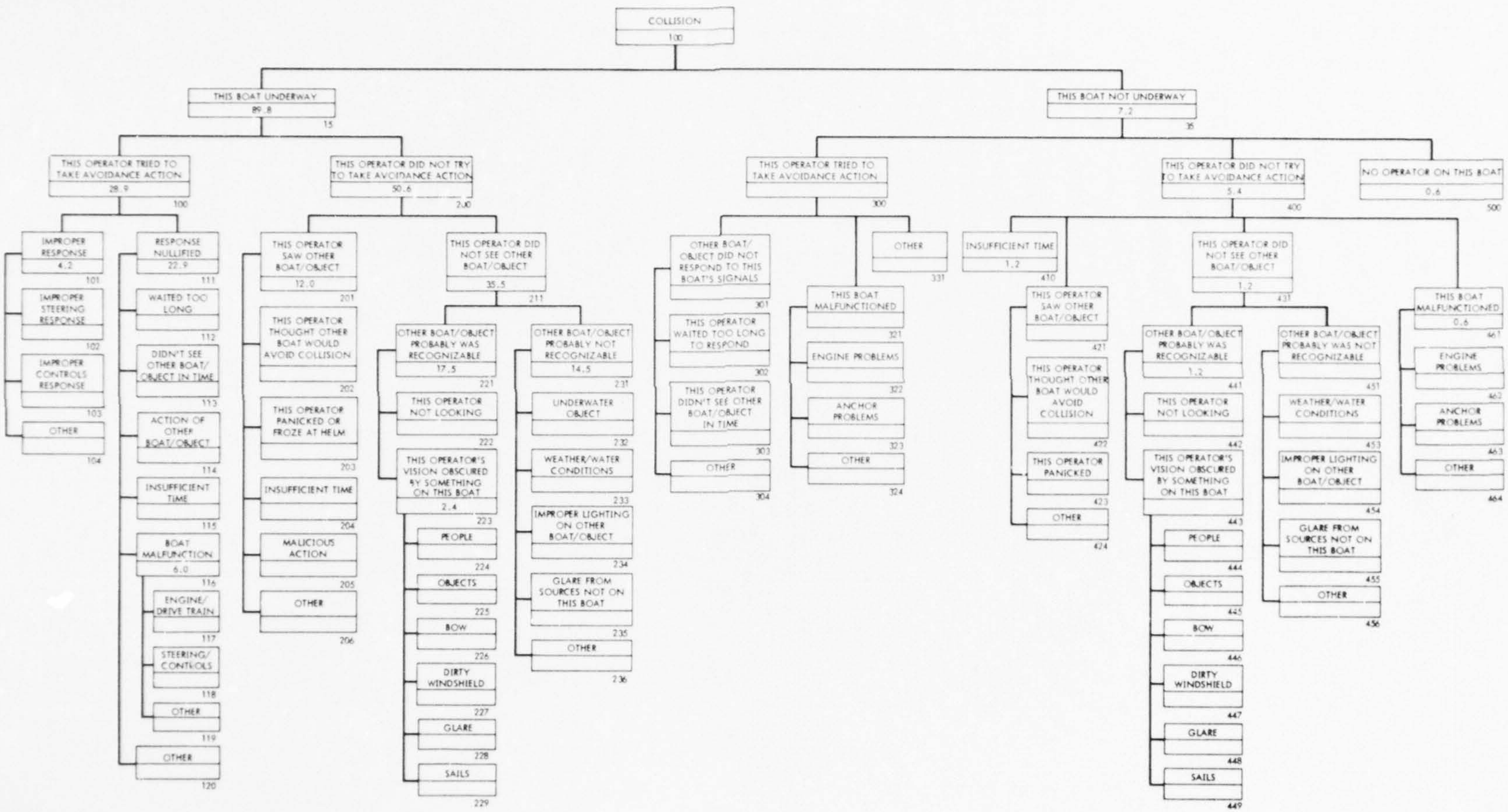


FIGURE 3-7. CUMULATIVE CAUSE PERCENTAGES IN ALL COLLISIONS

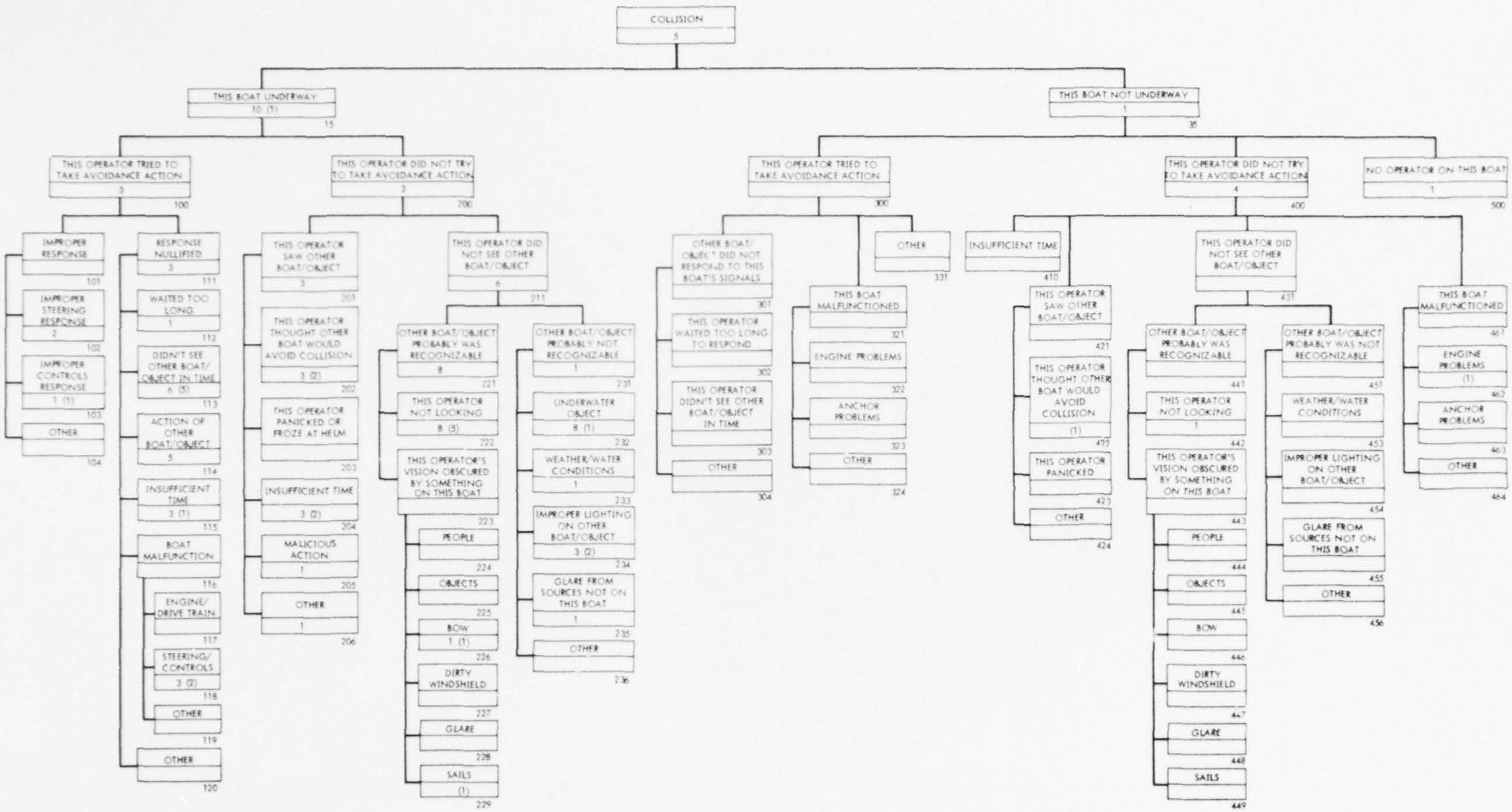


FIGURE 3-8. CAUSES CODED FROM BAR AND MIO REPORTS AND FROM IN-DEPTH REPORTS *

* In-depth report cause frequencies in parentheses, ( ).

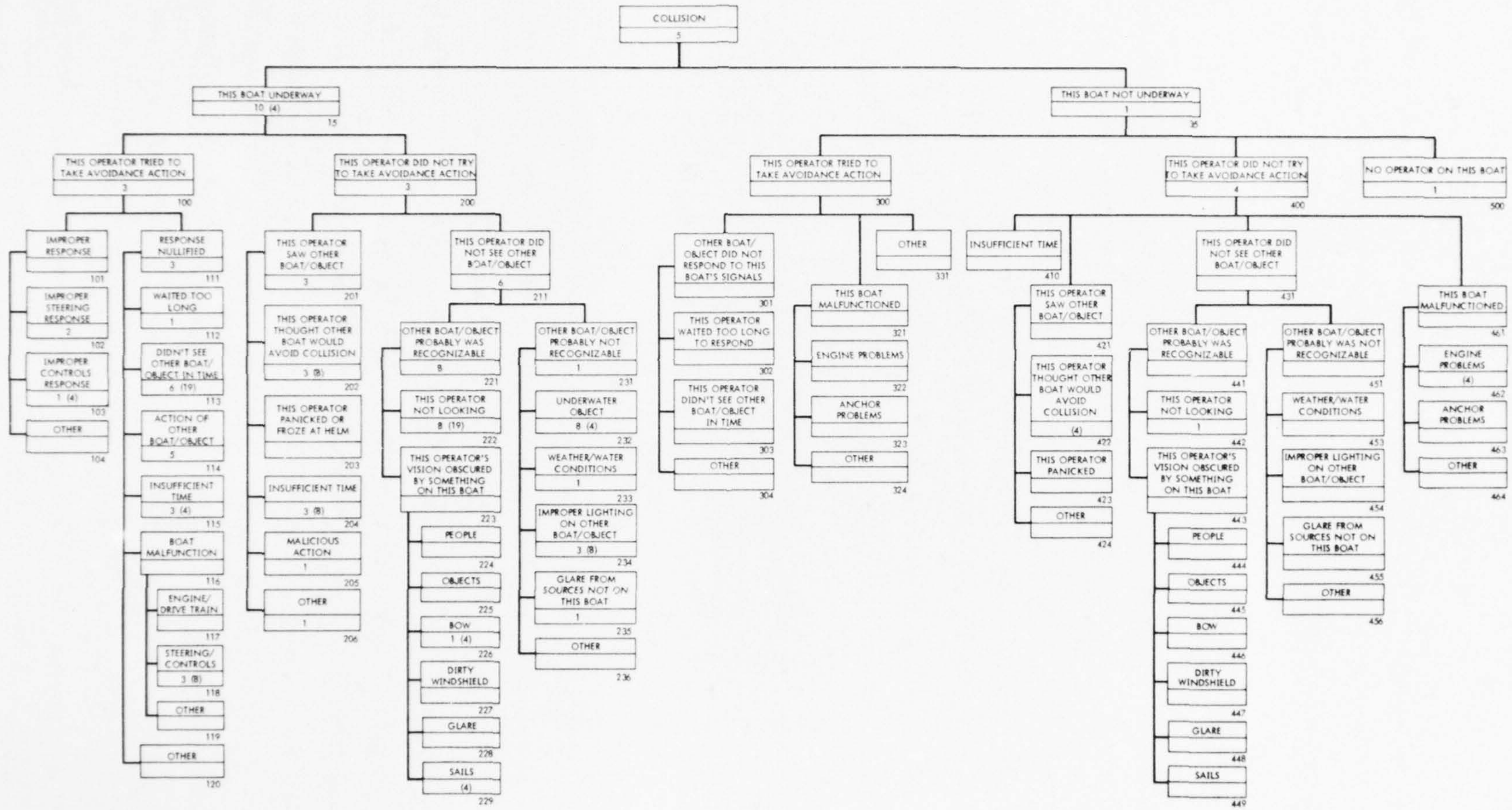


FIGURE 3-9. PERCENTAGES OF CAUSES CODED FROM BAR AND MIO REPORTS AND FROM IN-DEPTH REPORTS *

* In-depth report cause percentages in parentheses, ( ).

corresponding percentages. The causes in the Collision Cause Coding Tree are only the overt collision causes determined from the reports. In-depth reports obviously contain much more detailed information on contributing causes. We could, however, determine how BAR and MIO reports compare with in-depth reports in yielding the overt cause data coded in the data analysis.

In examing Figure 3-8 it was found that fifty-seven of the 100 boat collision cause analyses from BAR and MIO reports yielded cause information at least as detailed as asked for on the Collision Cause Coding Tree. The numbers for in-depth collisions were twenty-five out of twenty-six. Thus, 57% of the analyses of BAR and MIO reports yielded collision cause information at least as detailed as was coded for, while 96% of the in-depth report analyses yielded such data. That this was a statistically significant difference was shown by the following Chi-Square test in which a significance level better than 0.05% was obtained.

57	43	100
25	1	26
82	44	126

$\chi^2 = 12.25;\ p < 0.05\%$

Figures 3-8 and 3-9 were also used to determine if a significant difference existed between the the causes coded from BAR and MIO reports and those coded from in-depth reports. Theoretically, a statistical test for coding differences in the entire tree would have been most appropriate; however, the usual such test is the Chi-Square test which could not be applied due to the small numbers of data points in most cells. A test based on the multinomial distribution (similar to the Fisher Exact test) also could not be applied due to the extreme number of calculations which would be involved. Instead, Figure 3-9 was examined for those causes showing the most extreme differences in coding percentages and those differences were tested using corrected Chi-Square or Fisher Exact tests on the corresponding data in Figure 3-8. As a comparison of the level of cause detail available in the reports was already made, the tests were restricted to causes at the most detailed level. The differences tested were those in Causes 113, 114, 118, 229 and 232. For those interested, the tables involved in the tests and the calculated probabilities follow. A discussion of the statistical tests will be found in Appendix B.

Cause 113

6	94	100
5	21	26
11	115	126

$\chi^2 = 3.02$; $p = 9\%$

Cause 114

5	95	100
0	26	26
5	121	126

Fisher; $p = 62\%$

Cause 118

3	97	100
2	24	26
5	121	126

Fisher; $p > 43\%$

Cause 229

0	100	100
1	25	26
1	125	126

Fisher; $p = 41\%$

Cause 232

8	92	100
1	25	26
9	117	126

Fisher; $p = 59\%$

Examining the results of the above tests, we found that with the exception of Cause 113 none of the differences between the percentage of BAR and MIO reports coded with a particular cause and the in-depth reports coded with the same cause came even close to being statistically significant. As the causes not tested involved even less extreme differences, they too would have shown no significant statistical differences. Finally, that one of the causes, in this case Cause 113, showed a 9% significance level was not surprising and indeed should have been expected. Considering the number of causes involved, it was to be expected that the random sampling process alone would result in at least one difference as extreme as that. Thus, we found no statistical reason to believe that BAR and MIO reports indicate overt collision causes that are different from those indicated by in-depth collision reports, except that in-depth reports did yield significantly more information.

In Figures 3-10, 3-11, 3-12, and 3-13 data on the causes of non-fatal and fatal collisions is presented. For two-boat collisions, if there was a fatality on either boat, the causes coded

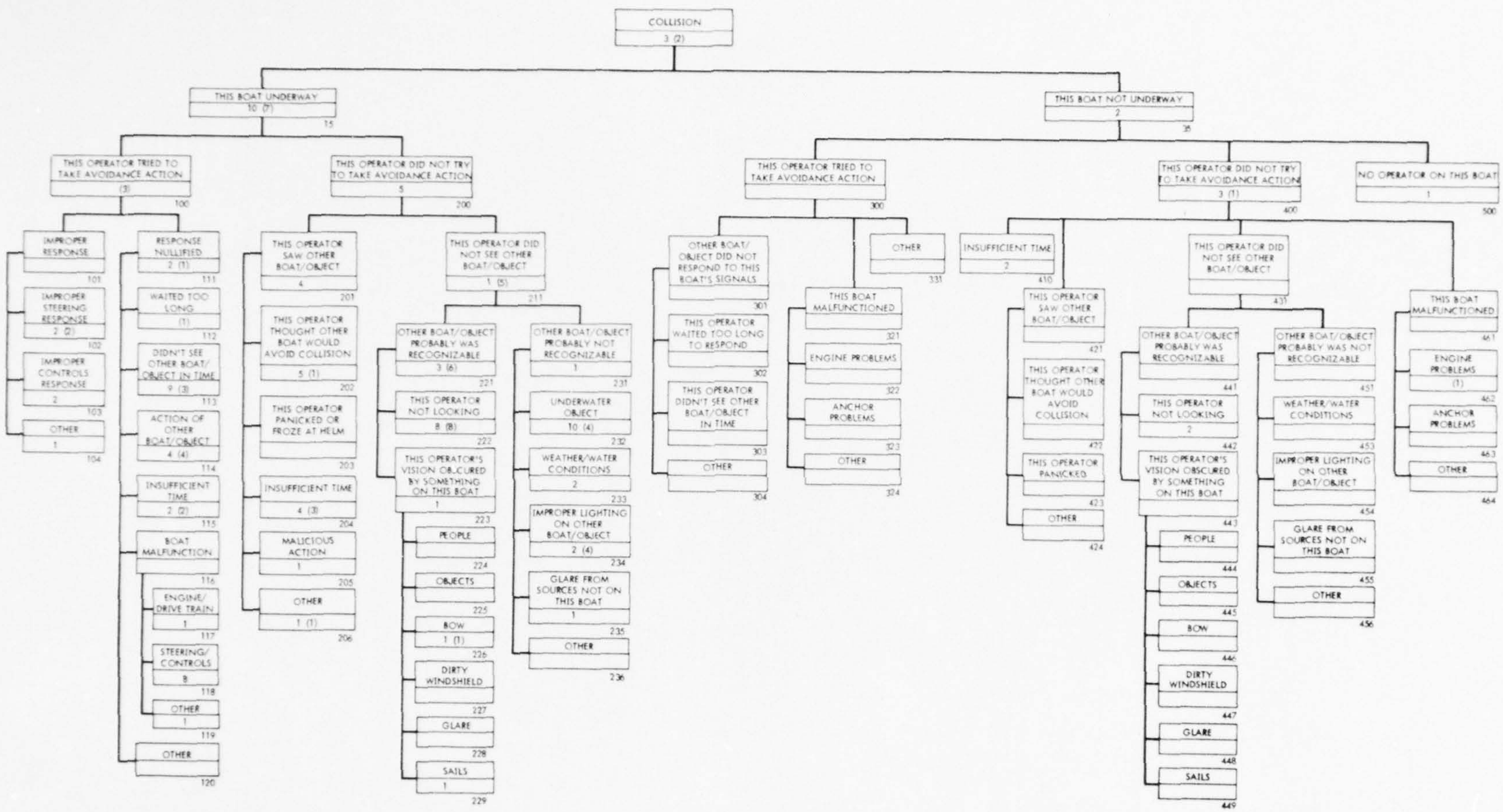


FIGURE 3-10. CAUSES IN NON-FATAL AND FATAL COLLISIONS *

* Fatal collision cause totals shown in parentheses, ( ).

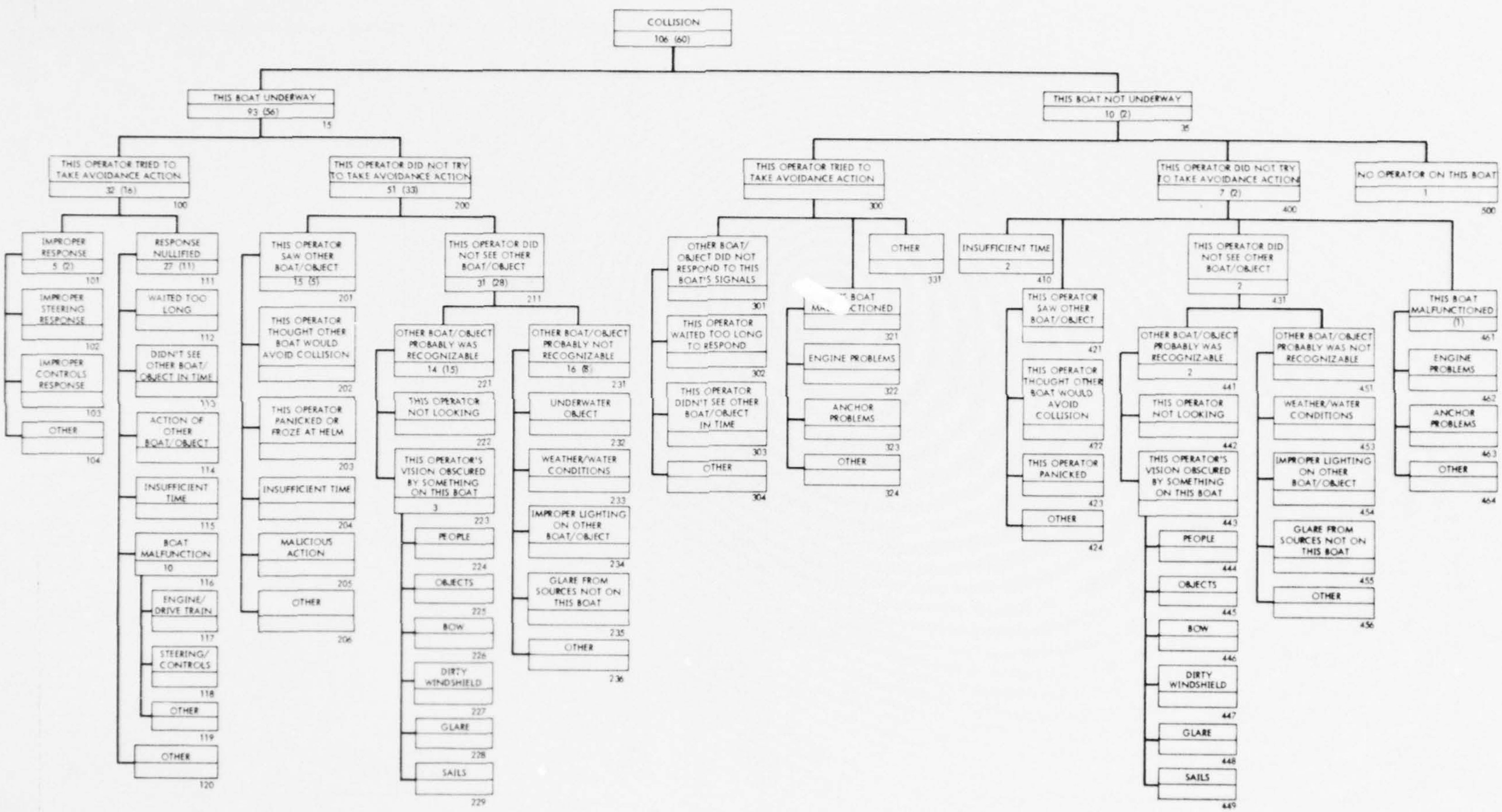


FIGURE 3-11. CUMULATIVE CAUSES IN NON-FATAL AND FATAL COLLISIONS *

* Fatal collision cause totals shown in parentheses, ( ).

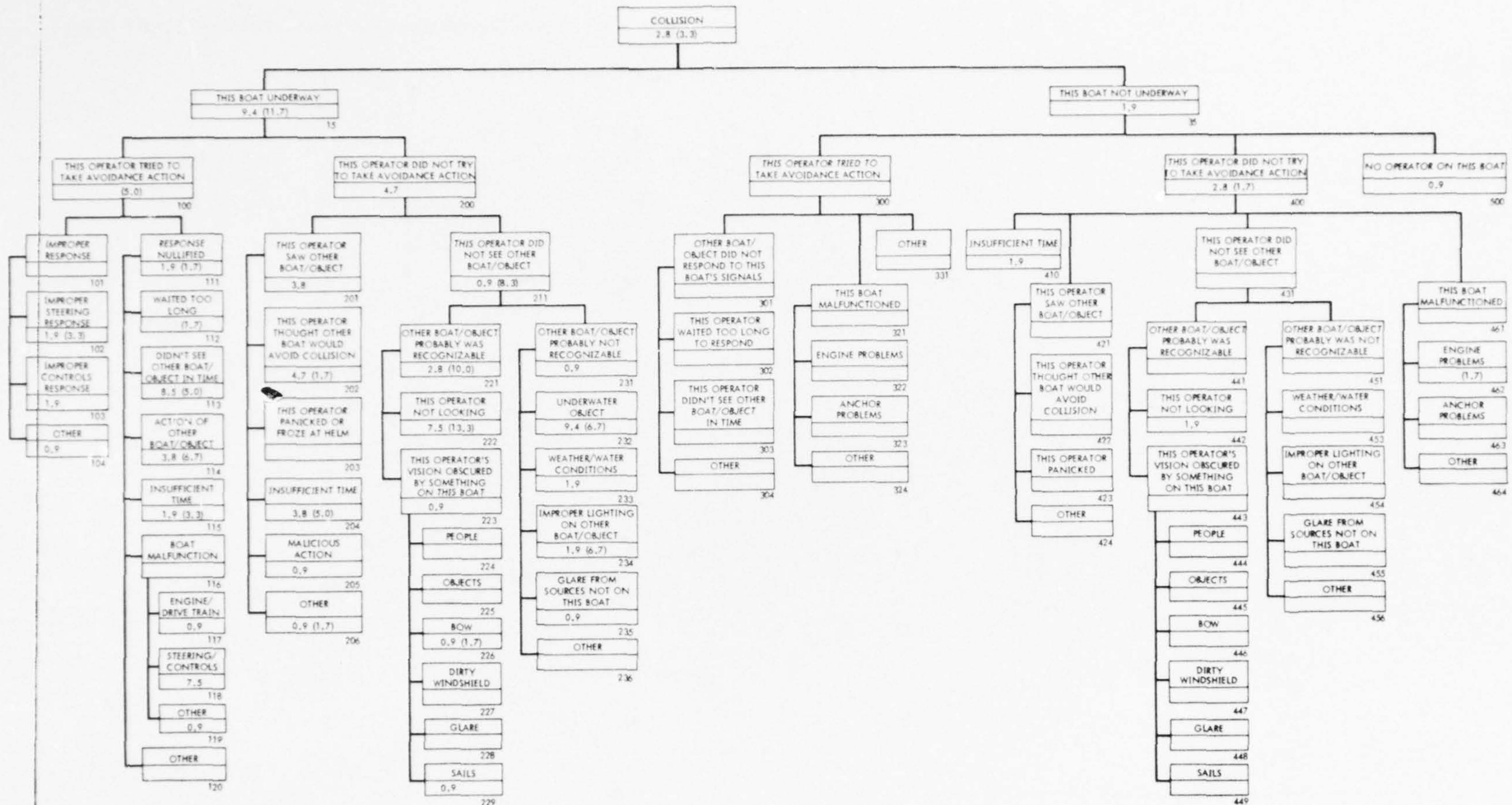


FIGURE 3-12. CAUSE PERCENTAGES IN NON-FATAL AND FATAL COLLISIONS *

* *Fatal collision cause percentages shown in parentheses, ( ).*

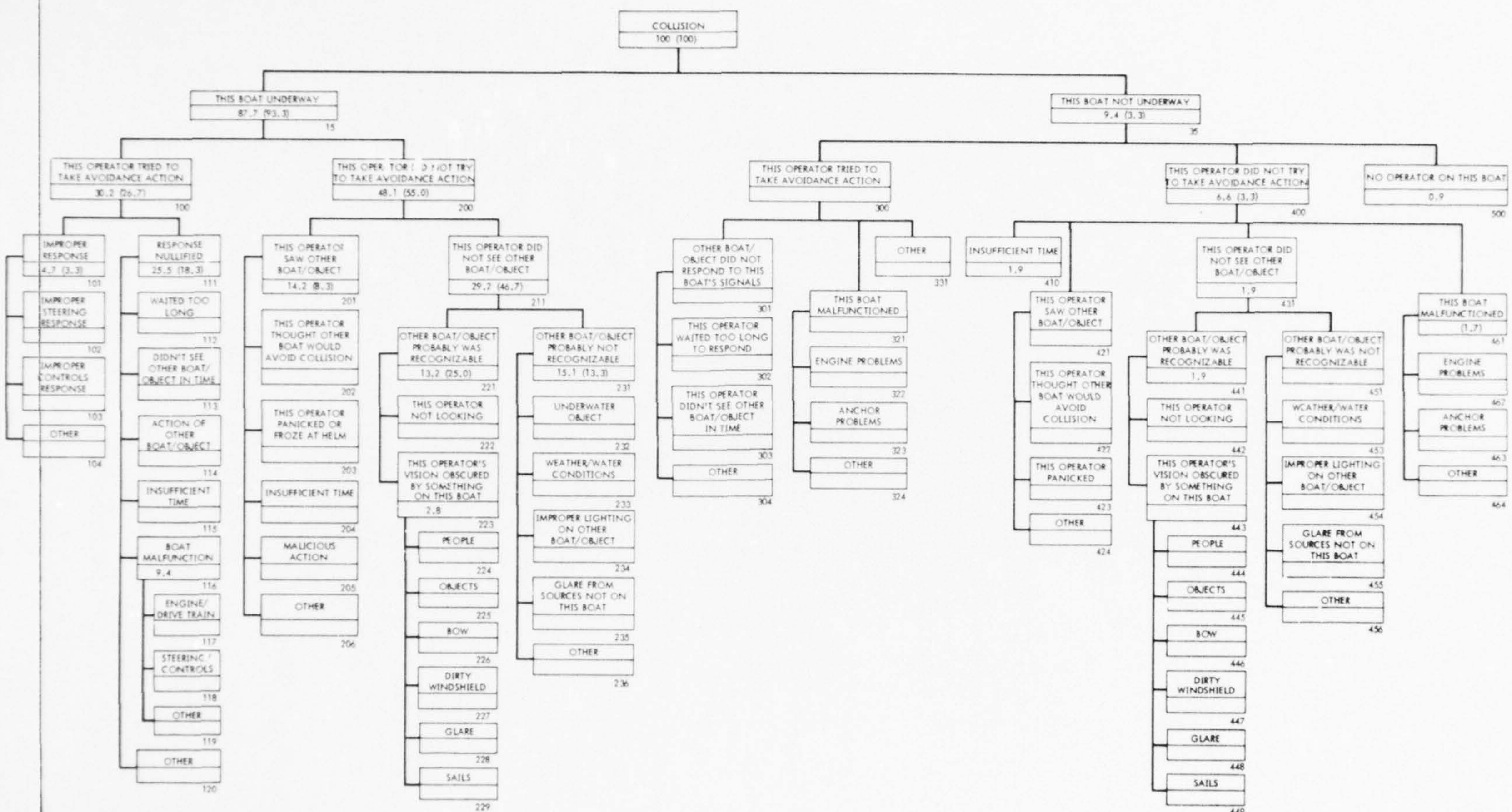


FIGURE 3-13. CUMULATIVE CAUSE PERCENTAGES IN NON-FATAL AND FATAL COLLISIONS *

* Fatal collision cause percentages shown in parentheses, ( ).

for both boats are included in the fatal collisions category. Figure 3-10 indicates the number of boats coded by each cause. In Figure 3-11 cumulative cause totals are shown. Figures 3-12 and 3-13 contain the cause totals converted to percents.

We examined the later two figures to see if there were any significant differences in the causes of non-fatal and fatal collisions. Percents which seemed significantly different for non-fatal and fatal collisions were tested by applying appropriate statistical tests to the data in Figures 3-10 and 3-11. The statistical tests used were the Fisher Exact test, used whenever there were less than five data points in a cell, and the corrected Chi-Square test, used when the data were more numerous. Descriptions and examples of these tests may be found in Appendix B. To spare the reader the tedium of reading through numerous, repetitive calculations, only the initial contigency table and the results of each test will be presented.

Causes which appeared in the sample to have significantly different probabilities of occurrence in non-fatal and fatal collisions were usually tested two ways. They were first tested for significant differences when compared against all other fatal, or non-fatal, collision causes. If the result of such a test was significant, or nearly so, a second test was made. This test compared cause frequencies against only those frequencies for boats in the same state of motion (underway, not underway) and for which there would be no ambiguity as to which data cell the frequencies should occupy. For instance, in the second test of Cause 211, the fifteen non-fatal instances of Causes 15 and 200 were not included, as these causes might have included some occurrences of Cause 211.

Examining Figures 3-12 and 3-13, we found that the following causes might possibly have significantly different probabilities of occurrence for non-fatal and fatal collisions.

Cause 118. Steering/Controls malfunction.
202. This operator thought other boat would avoid collisions.
222. This operator not looking.
234. Improper lighting on other boat/object.
116. Boat malfunction (cumulative).
201. This operator saw other boat/object (cumulative).
211. This operator did not see other boat/object (cumulative).
221. Other boat/object probably was recognizable (cumulative).

Statistical tests of these causes were made as follow: In each case, the initial contingency table is shown, the type of test is indicated and the appropriate significance level p of the test result is given. Unless otherwise specified, all tests on the cause data are tests of the null hypothesis that there is no difference in the relative frequencies of occurrence of the causes in fatal and non-fatal accidents versus the hypothesis that such a difference exists.

Cause 118.	First Test			Second Test		
	8	98	106	8	73	81
	0	60	60	0	45	45
	8	158	166	8	118	126
	Fisher; $p = 4.9\%$			Fisher; $p = 5.1\%$		

Cause 202.	First Test			Second Test
	5	101	106	Not computed due to non-significant result on first test.
	1	59	60	
	6	160	166	
	Fisher; $p > 45.8\%$			

Cause 222.	First Test			Second Test
	8	96	106	Not computed due to non-significant result on first test
	8	52	60	
	16	148	166	
	$\chi^2 = 0.798$; $p > 30\%$			

Cause 234.	First Test			Second Test
	2	104	106	Not computed due to non-significant result on first test
	4	56	60	
	6	160	166	
	Fisher; $p = 26.4\%$			

Cause 116. (Cumulative)	First Test			Second Test		
	10	96	106	10	71	81
	0	60	60	0	45	45
	10	156	166	10	116	126
	Fisher; p = 1.9%			Fisher; p = 1.9%		

Cause 201. (Cumulative)	First Test			Second Test
	15	91	106	Not computed due to non-significant result on first test
	5	55	60	
	20	146	166	
	$\chi^2 = 0.736$; $p > 35\%$			

Case 211. (Cumulative)	First Test			Second Test		
	31	75	106	31	47	78
	28	22	60	28	21	49
	59	97	166	59	68	127
	$\chi^2 = 8.13$; $p < 0.5\%$			$\chi^2 = 3.00$; $5\% < p < 10\%$		

Cause 221. (Cumulative)	First Test			Second Test		
	14	92	106	14	63	77
	15	45	60	15	34	49
	29	137	166	29	97	126
	$\chi^2 = 2.92$; $5\% < p < 10\%$			$\chi^2 = 1.96$; $10\% < p < 20\%$		

Examining the results of these tests and the percentages in Figures 3-12 and 3-13, we find that only tests of Causes 118, 116 (cumulative) and 211 (cumulative) showed results significant at the 5% (or better) level.

From these results it appears that boat malfunctions, especially steering or control malfunctions, account for a larger proportion of non-fatal collisions than fatal ones. This should not be interpreted, however, to mean that such malfunctions do not cause fatal collisions.

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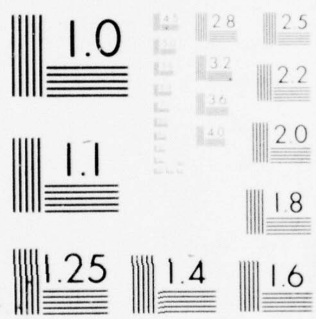

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

The significant test results for Cause 211 indicate what one would expect. That is, a proportionally higher percentage of collisions are fatal than non-fatal when an operator does not take any avoidance action.

We now turn to an examination of accident causes with respect to different boat lengths. Boat lengths were divided into three classes: less than 16 ft (4.88 m), 16 ft (4.88 m) to less than 26 ft (7.92 m), and 26 ft (7.92 m) or greater. Figures 3-14 and 3-15 contain the frequency data while Figures 3-16 and 3-17 contain the corresponding percentages (given only to the nearest percent so that percentages for all three categories could be displayed in the same figure).

In examining this data, we are interested not just in differences among the percentages, but more particularly in a pattern in them, that is, do any cause percentages tend to increase or decrease as a function of boat length.

The usual statistical test for testing this type of data involves using a Chi-Square test with two degrees of freedom on a 3 x 2 contingency table. However, in many cases our data is insufficient to satisfy minimum cell size requirements. In such cases, Fisher Exact tests were performed on 2 x 2 contingency tables. The choice of which boat lengths to use in defining the cells of the 2 x 2 table is based on the nature of the cause and a determination of which choice will lead to the most significant result. As with non-fatal vs. fatal accidents, two tests are sometimes performed: a first test based on all cause data and (possibly) a second test based only on unambiguous causes for boats in the same state of motion.

An examination of Figures 3-16 and 3-17 suggests that the following causes may have statistically significant differences in probability of occurrence as a function of boat length.

Cause	102.	Improper steering response.
	103.	Improper controls response.
	113.	Didn't see other boat/object in time.
	114.	Action of other boat/object.
	115.	Insufficient time.

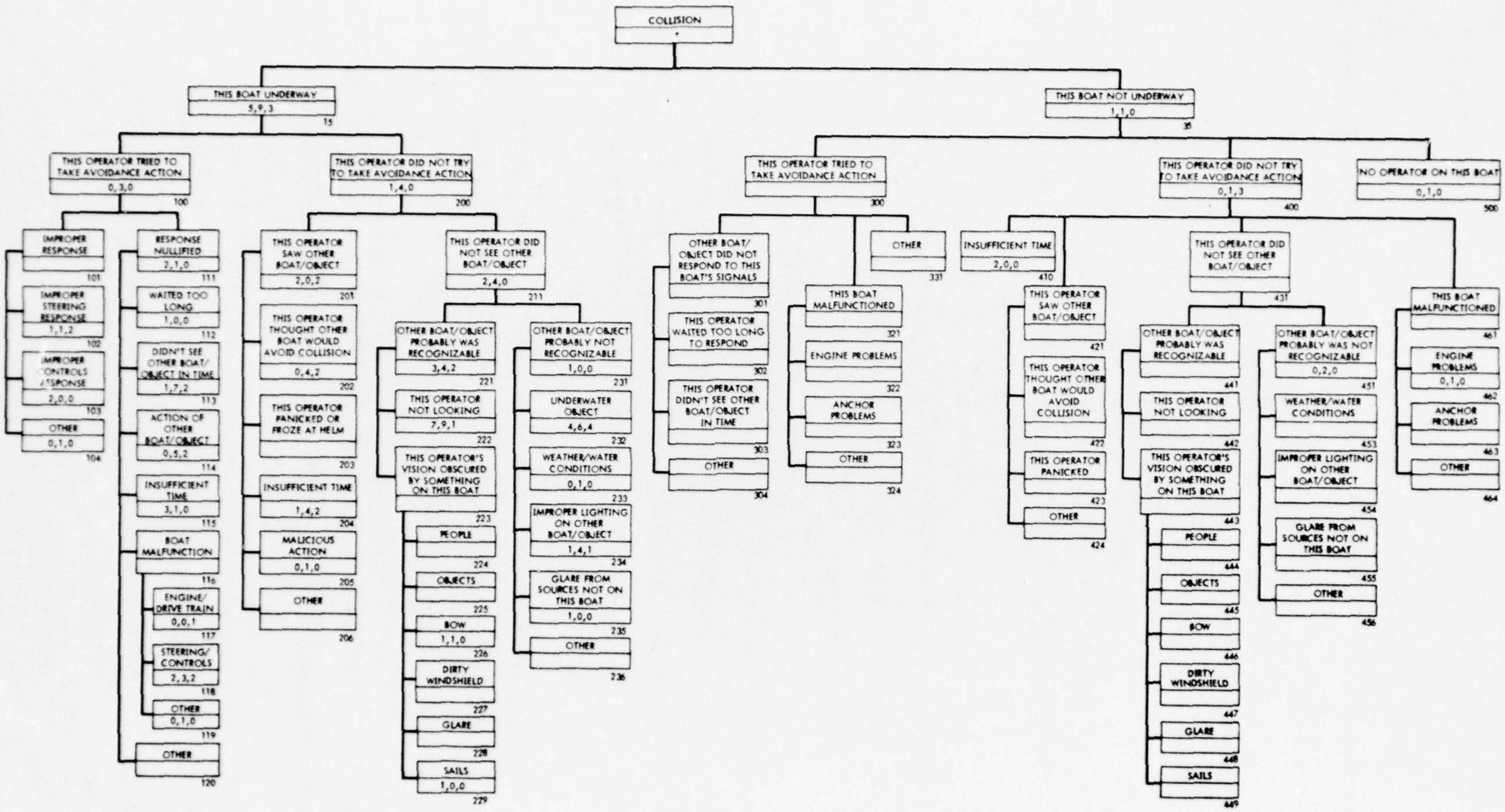

FIGURE 3-14. COLLISION CAUSES BY BOAT LENGTH X

($X < 16$ ft, 16 ft $\leq X < 26$ ft, $X \geq 26$ ft)

($X < 4.88$ m, 4.88 m $\leq X < 7.92$ m, $X \geq 7.92$ m)

* Category omitted - Unnecessary for analyses performed and data insufficient.

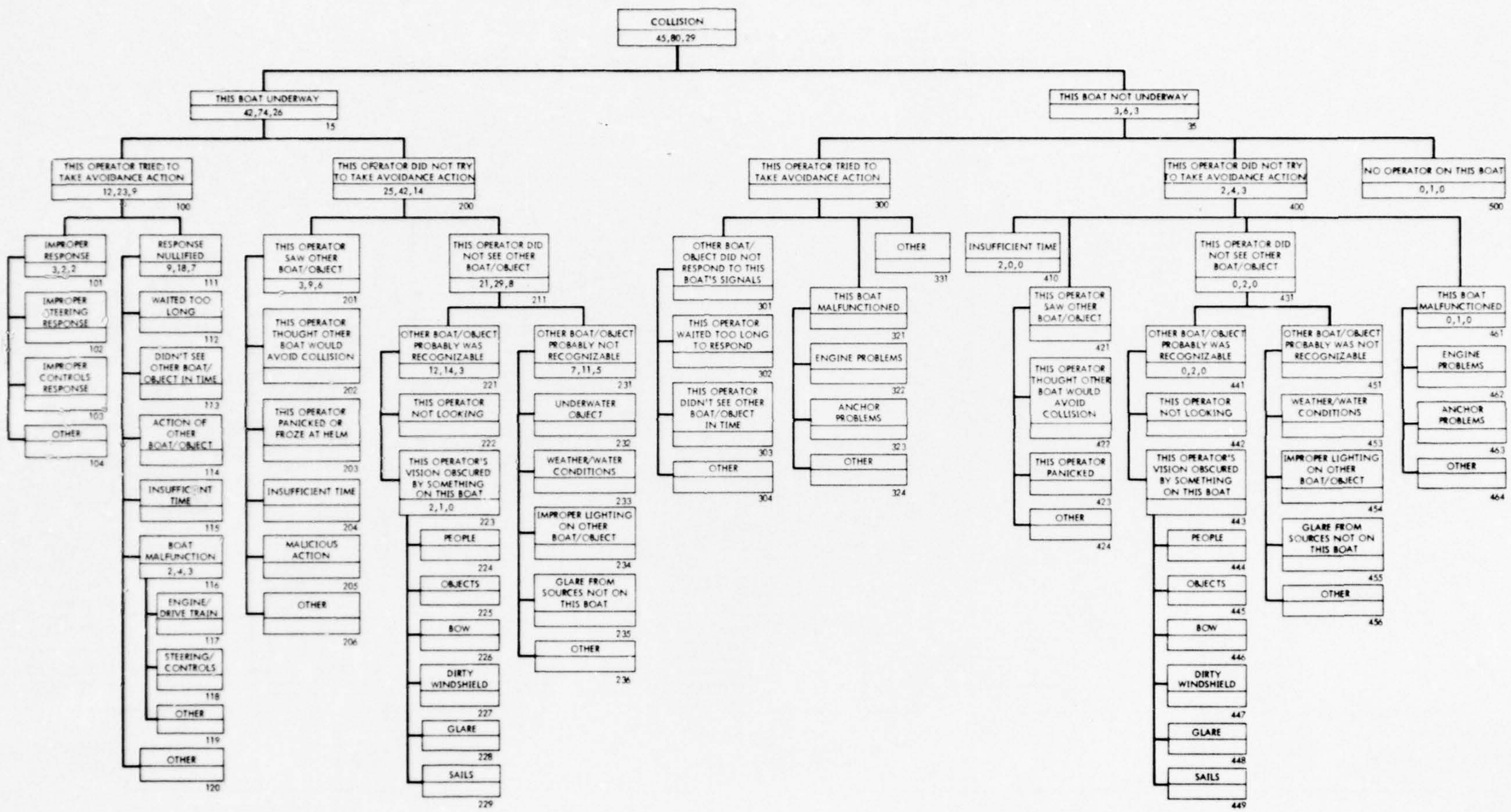

FIGURE 3-15. CUMULATIVE COLLISION CAUSES BY BOAT LENGTH X

($X < 16$ ft, 16 ft $\leq X < 26$ ft, $X \geq 26$ ft)

($X < 4.88$ m, 4.88 m $\leq X < 7.92$ m, $X \geq 7.92$ m)

* Category omitted - Unnecessary for analyses performed and data insufficient.

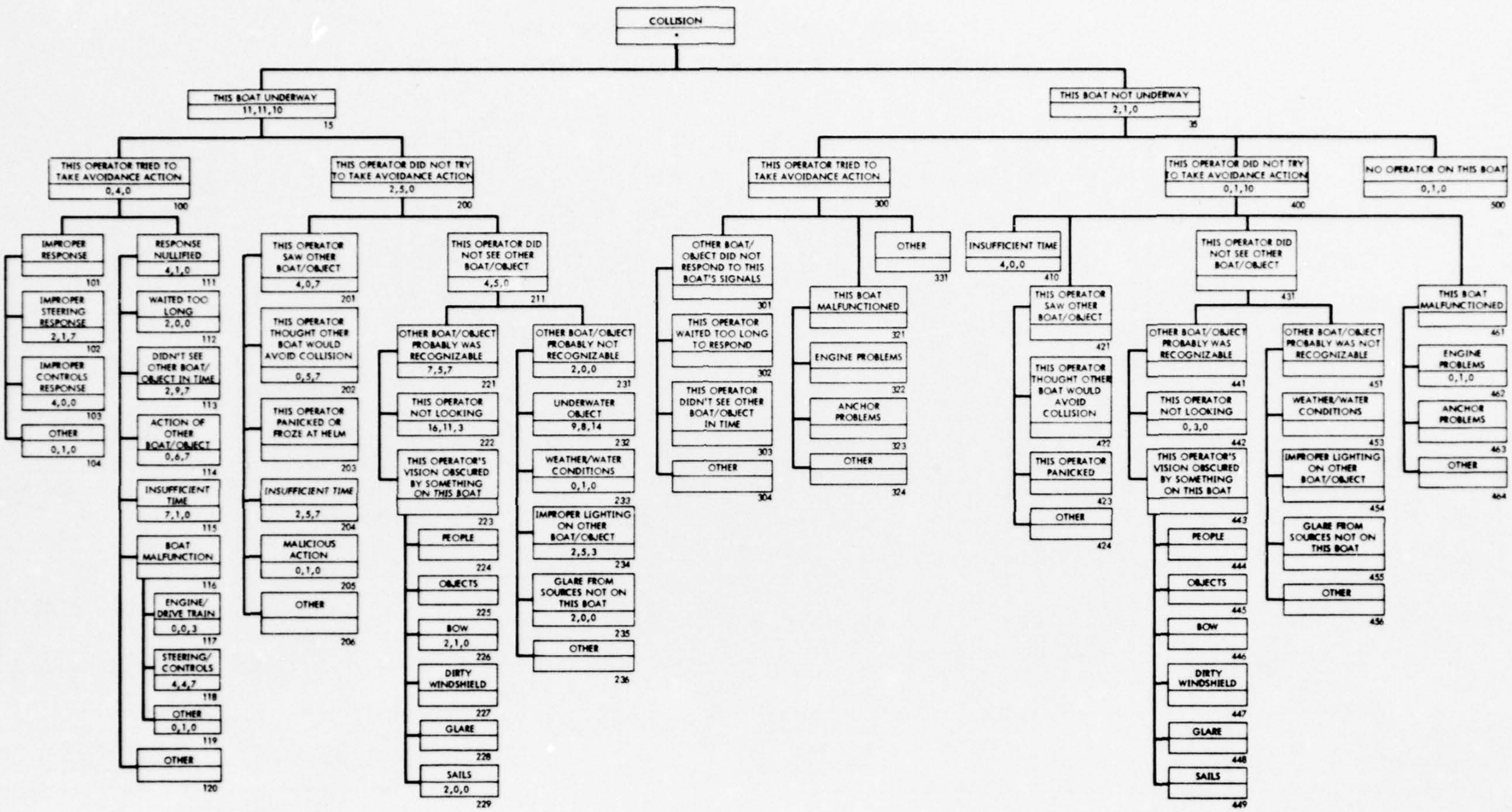

FIGURE 3-16. COLLISION CAUSE PERCENTAGES BY BOAT LENGTH X
(X < 16 ft, 16 ft ≤ X < 26 ft, X ≥ 26 ft)
(X< 4.88 m, 4.88 m ≤ X< 7.92 m, X ≥ 7.92 m)

* Category omitted - Unnecessary for analyses performed and data insufficient.

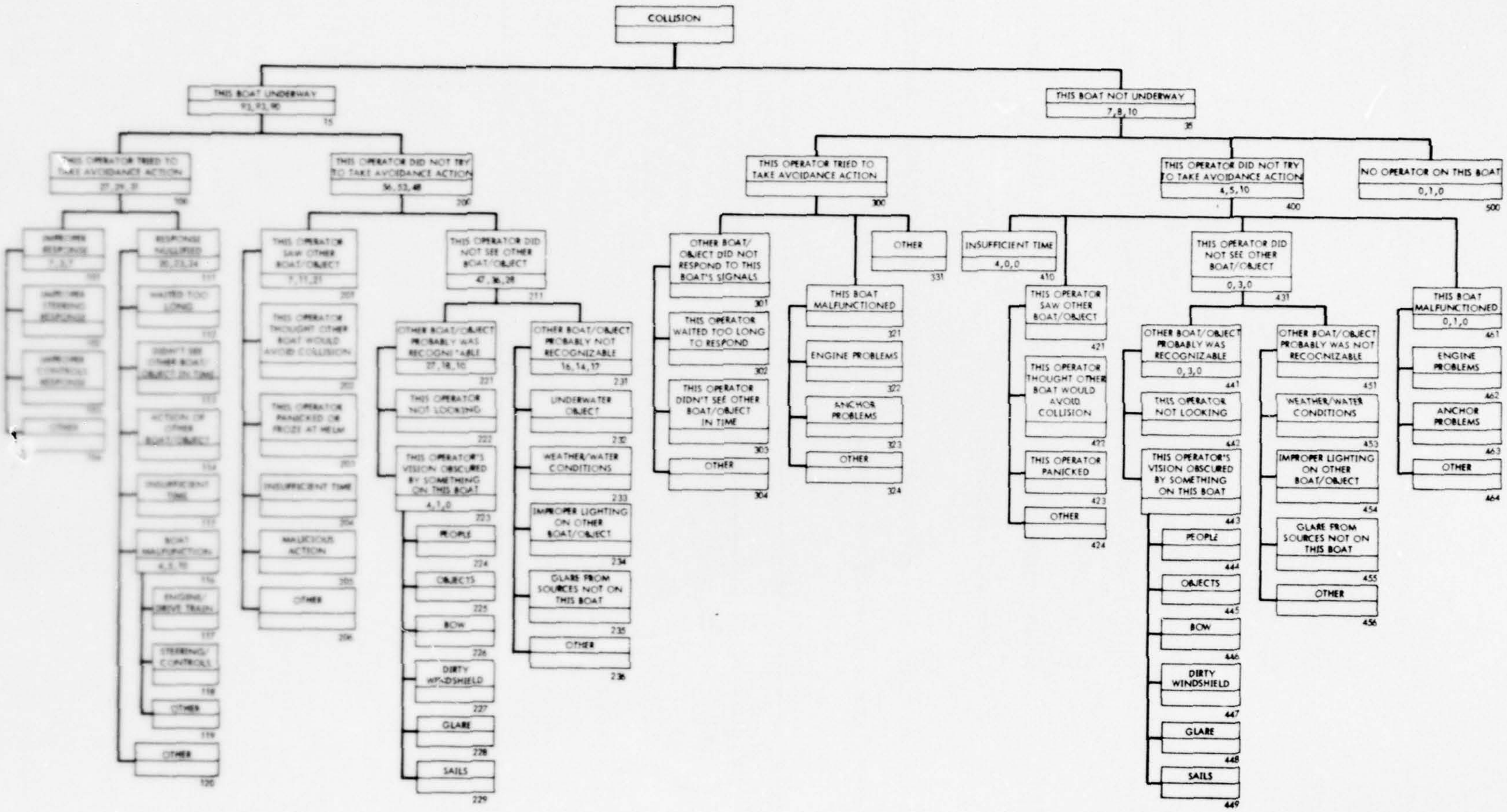

FIGURE 3-17. CUMULATIVE COLLISION CAUSE PERCENTAGES BY BOAT LENGTH X
($X < 16$ ft, 16 ft $\leq X < 26$ ft, $X \geq 26$ ft)

($X < 4.88$ m, 4.88 m $\leq X < 7.92$ m, $X \geq 7.92$m)

Cause (con't) 202. This operator thought other boat would avoid collisions.

204. Insufficient time.

222. This operator not looking.

116. Boat malfunction (cumulative).

201. This operator saw other boat/object (cumulative).

221. Other boat/object probably was recognizable (cumulative).

223. This operator's vision obscured by something on this boat (cumulative).

400. This operator did not try to take avoidance action (boat not underway) (cumulative).

The following statistical tests were performed on data for the above causes. As before p is the approximate significance level of the test results.

Cause 102.	First Test			Second Test
	$16' \leq X < 26'$ vs $X \geq 26'$ *			Not computed due to non-significant result on first test
	1	79	80	
	2	27	29	
	3	106	109	
	Fisher; $p > 30\%$			

* $4.88\ m \leq X < 7.92\ m$ vs $X \geq 7.92\ m$

Cause	First Test	Second Test
Cause 103.	X<16' vs X≥16' *	X<16' vs X≥16' *
	2 | 43 | 45	2 | 35 | 37
	0 | 109 | 109	0 | 85 | 85
	2 | 152 | 154	2 | 120 | 122
	Fisher; p = 16.8%	Fisher; p = 18.0%
Cause 113.	X<16' vs X≥16' *	Not computed due to non-significant result on first test
	1 | 44 | 45	
	9 | 100 | 109	
	10 | 144 | 154	
	Fisher; p > 25.0%	
Cause 114.	X<16' vs X≥16' *	X<16' vs X≥16' *
	0 | 45 | 45	0 | 35 | 35
	7 | 102 | 109	7 | 77 | 84
	7 | 147 | 154	7 | 112 | 119
	Fisher; p = 16.8%	Fisher; p = 16.2%
Cause 115.	X<16' vs X≥16' *	X<16' vs X≥16' *
	3 | 42 | 45	3 | 32 | 35
	1 | 108 | 109	1 | 83 | 84
	4 | 150 | 154	4 | 115 | 119
	Fisher; p = 15.1%	Fisher; p = 15.2%
	X < 26' vs X ≥ 26' **	X< 26' vs X ≥ 26'
	8 | 117 | 125	Not computed due to non-significant result on first test
	0 | 29 | 29	
	8 | 146 | 154	
	Fisher; p = 36.1%	

* X< 4.88 m vs X ≥ 4.88 m

** X< 7.92 m vs X ≥ 7.92 m

Cause 202.	First Test	Second Test
	$X < 16'$ vs $X \geq 26'$ *	Not computed due to non-significant result on first test
	0 45	45 2 27	29 2 72	74	
	Fisher; p = 30.1%	
	$X < 16'$ vs $X \geq 16'$ **	$X < 16'$ vs $X \geq 16'$ Not computed due to non-significant result on first test
	0 45	45 6 103	109 6 148	154	
	Fisher; p = 24.1%	

Case 204.

As the percentage differences for this cause are less extreme than those for Cause 202 and tests of Cause 202 yielded non-significant results, tests of this cause will also yield non-significant results.

Cause 222.	First Test			Second Test
	7 (5.0)	38 (40.0)	45	Not computed due to non-significant result on first test
	9 (8.8)	71 (71.2)	80	
	1 (3.2)	28 (25.8)	29	
	17	137	154	
	$\chi^2_2 = 2.61$, $p > 20\%$			

Cause 116 (cumulative).

Comparing the data for this cause with that of Cause 202, it is clear that statistical tests on this cause data will yield non-significant results as they did for Cause 202.

* $X < 4.88$ m vs $X \geq 7.92$ m

** $X < 4.88$ m vs $X \geq 4.88$ m

Cause 201. (cumulative)	First Test			Second Test		
	3 (5.3)	42 (39.7)	45	3 (5.4)	33 (30.6)	36
	9 (9.4)	71 (70.6)	80	9 (9.2)	52 (51.9)	61
	6 (3.4)	23 (25.6)	29	6 (3.5)	17 (19.6)	23
	18	136	154	18	102	120
	$\chi^2_2 = 3.40$; $p = 20\%$			$\chi^2_2 = 3.39$, $p = 20\%$		

Cause 221. (cumulative)	First Test			Second Test		
	12 (8.5)	33 (36.5)	45	12 (8.6)	22 (25.4)	34
	14 (15.1)	66 (64.9)	80	14 (14.5)	43 (42.5)	57
	3 (5.5)	26 (23.5)	29	3 (5.9)	20 (17.1)	23
	29	125	154	29	85	114
	$\chi^2_2 = 3.31$; $p = 20\%$			$\chi^2_2 = 3.73$; $p = 16\%$		

Cause 223 (cumulative).

Comparing the data for this cause with that of Cause 202, we see that differences are less extreme in this case. As statistical tests of Cause 202 data yielded non-significant results, the data for this cause will also yield non-significant results.

Cause 400 (cumulative).

This data is identical to that for Cause 116, and thus, statistical tests of this data would yield non-significant results.

Examining the results of the above tests, we find that not one of them yielded a statistically significant result. Thus, we have no reason to believe that the particular cause of a collision is related to the length of the involved boat.

Turning to actual boat malfunctions, we find that 6.6% of the sample collision causes were classified as boat malfunctions. Additionally, equipment malfunctions may have been at least partially responsible for collisions ascribed to other causes. Wyle researchers divided the cause blocks into three categories: causes that were definitely malfunction related, causes that were possibly malfunction related, and causes that were not likely to be malfunction related. Figure 3-18 shows the cause frequencies for all sample collisions and identifies the malfunction-related causes.

In addition to the eleven causes (6.6%) which were malfunctions, there were six instances (3.6%) in which an equipment malfunction might possibly have been involved. Thus, up to 10.2% of all collisions might be eliminated by eliminating boat or equipment malfunctions.

In the next section we analyze the stressor data obtained from the collision reports. As was mentioned in the first paragraph of Section 1.0, initial results indicated that 90% of the causes of the collisions studied in 1974 research were operator error-related. This information justified the study of stressors which was subsequently undertaken. To determine if the 90% figure held in the 1975 analysis of collision reports, Wyle analysts divided the collision cause blocks into three categories: causes which were probably operator-related, causes which were possibly operator-related and causes which were not likely to be operator-related. Included as possibly operator-related were causes such as boat malfunction which could have been due to improper maintenance or operation.

Figure 3-19 shows the cause frequencies for all sample collisions and identifies the operator-related causes. Of the causes coded, 27.7% were probably operator-related and an additional 59.0% were possibly operator-related. Thus, it was estimated that 86.7% of the coded causes were possibly operator-related. Although this is not precisely the same as stating that this percentage of causes were operator error-related, it is the most that can be stated based on the coding used.

The classification of causes was made independently of and without regard to the 1974 research results. Undoubtedly, as a result the classifications are conservative. That is, using the Bayesian approach of taking the 1974 results (i.e., 90%) into account, cause blocks would

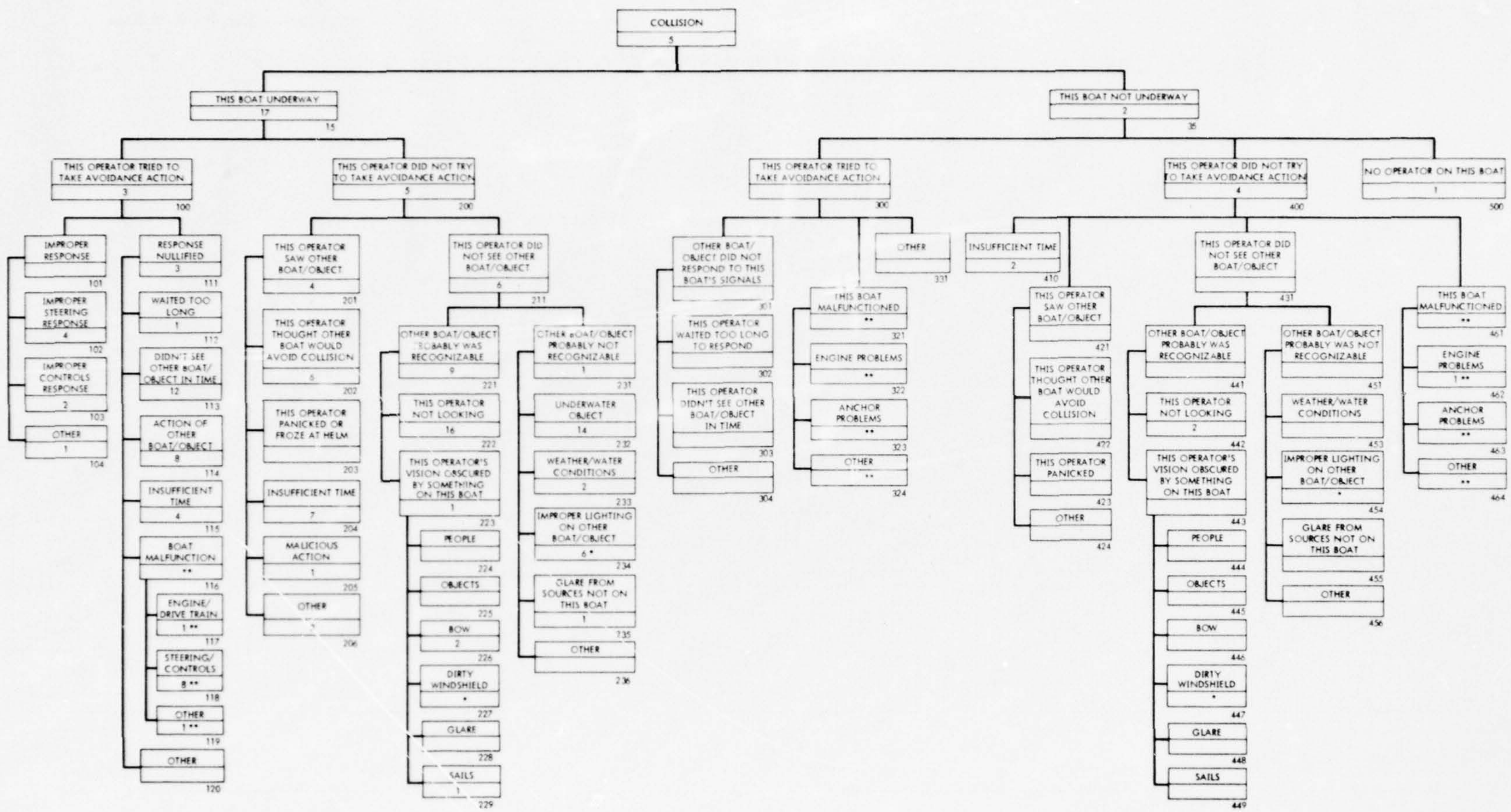

FIGURE 3-18. CAUSES IN ALL COLLISIONS WITH ASSOCIATED MALFUNCTION RELATIONSHIPS

* Possibly malfunction-related
** Definitely malfunction-related

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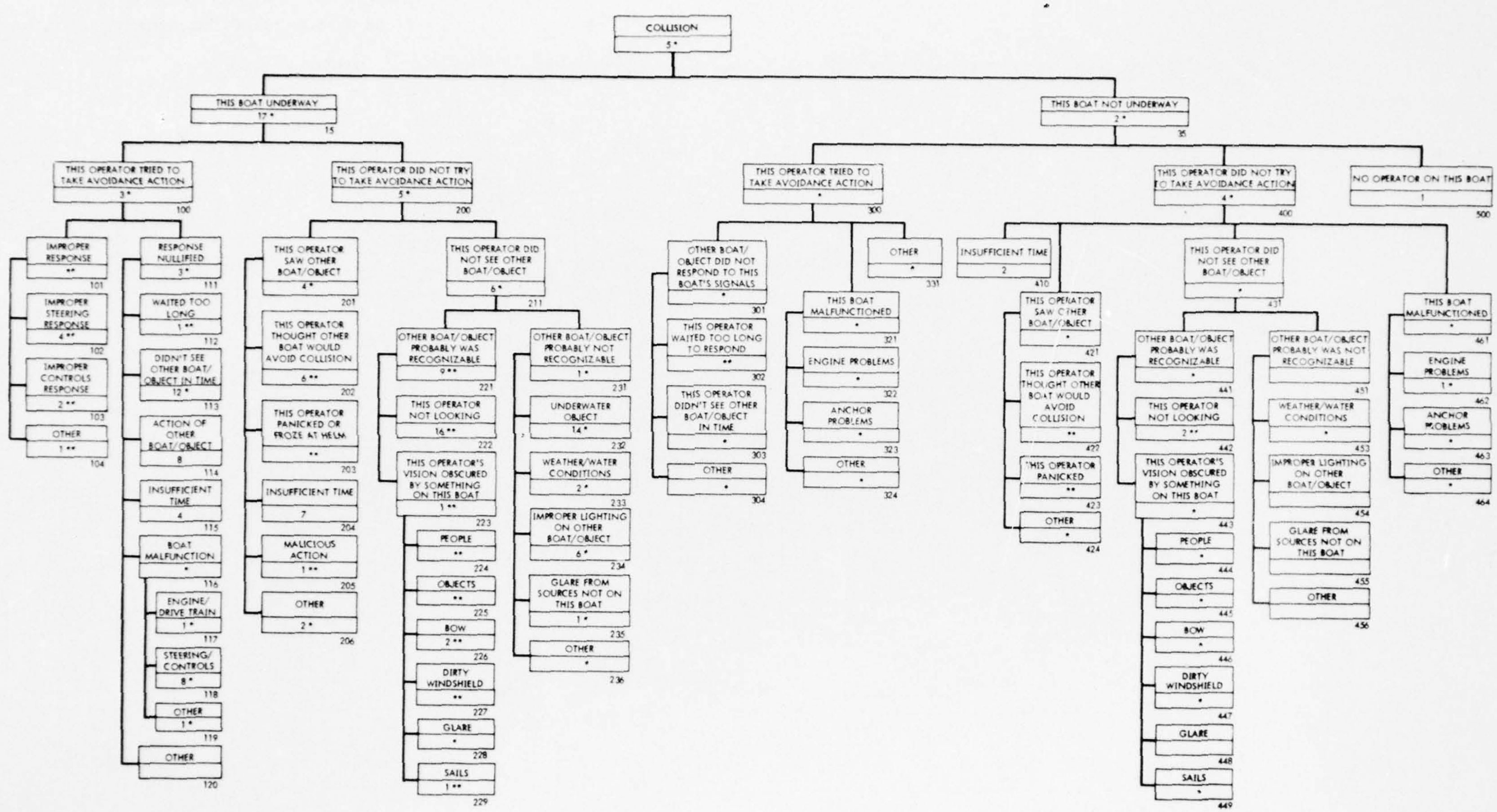


FIGURE 3-19. CAUSES IN ALL COLLISIONS WITH ASSOCIATED OPERATOR RELATIONSHIPS

* Possibly operator-related
** Probably operator-related

have been coded "probably operator-related" instead of "possibly operator-related." Also, the "insufficient time" causes might have been coded as "possibly operator-related." Thus, in view of the conservative nature of the classifications used it appears that the 1975 results are not out of line with the 1974 results.

3.5 Analysis of Stressors

One of the purposes of this effort was to attempt to gain stressor information from accident reports and to relate such information to collision causes. It was furthermore hoped that it would be possible to relate the results of the VAST experiments to this information. This section describes the results of this effort.

In Table 3-1 we saw that stressor information available from collision reports, other than in-depth reports, is virtually non-existent. Consequently, the stressor percentages given in Table 3-2 may be biased, as a "yes" answer may have been more likely to have been included in an accident report than a "no" answer, or conversely.

Keeping this caveat in mind, we examine some relationships among the data gathered on the human factors questionnaire. In each instance a Fisher exact test is performed on the contingency table to determine if the sample data indicates that a relationship exists between the two variables. For each pair of variables the initial contingency table is shown and the approximate significance level is given. Additionally, the value of the odds ratio contingency coefficient (see Appendix B) is presented when the significance level p is better than 5%. All tests will be first shown and then conclusions regarding the test results will be given.

Shock/Vibration vs Noise

	Yes	No	
Yes	12	0	12
No	0	6	6
	12	6	18

Fisher; $p = 0.0108\%$; $o = \infty$ (undefined)

Shock/Vibration vs Out of Control

	Yes	No	
Yes	5	8	13
No	1	6	7
	6	14	20

Fisher; $p > 46\%$

Human Engineering Problems vs Out of Control

	Yes	No	
Yes	5	11	16
No	1	1	2
	6	12	18

Fisher; $p > 94\%$

Human Engineering Problems vs Proper Position

	Yes	No	
Yes	7	7	14
No	2	0	2
	9	7	16

Fisher; $p > 60\%$

Reckless vs Speeding

	Yes	No	
Yes	29	16	45
No	2	26	28
	31	42	73

Fisher; $p = 1.3 \times 10^{-4}\%$; $o = 23.56$

Reckless vs Drinking

	Yes	No	
Yes	14	5	19
No	0	6	6
	14	11	25

Fisher; $p = 0.52\%$; $o = \infty$ (undefined)

Reckless vs Sober

	Yes	No	
Yes	5	13	18
No	5	0	5
	10	13	23

Fisher; p = 1.5%; o = 0, (inverse relationship)

Reckless vs Shock/Vibration

	Yes	No	
Yes	9	5	14
No	3	2	5
	12	7	19

Fisher; p>80%

We see that we only get significant results ($p \leq 5\%$) in those cases where it would be certainly expected, namely in shock/vibration vs noise, reckless vs speeding, reckless vs drinking, and reckless vs sober. There are three possible explanations for no other relationships being found. First, as these relationships are expected whereas the others are not, these are the only ones looked for or reported. Secondly, it may be that while relationships in some of the other cases exist, they might be much weaker, and consequently a much larger data base may be needed to achieve reasonable significance levels. Finally, it may be that no relationship exists between the other pairs of variables tested. Further research, including in-depth investigations would be needed to determine which of these explanations is the correct one.

The results of the VAST experiments indicated that the following stressors or combinations of stressors at the indicated levels resulted in operator performance degradation.

High fatigue vs low fatigue (approximately equivalent to over four hours on boat outing vs under one hour on outing)

High noise and high glare vs low noise and low glare

Drinking vs non-drinking

High shock and high noise vs low shock and high noise vs low shock and low noise

The data base was examined for these stressor combinations and the corresponding collision cause in each instance was tabulated. Figures 3-20, 3-21, 3-22, and 3-23 are reproductions of Figure 3-4 on which the results of these tabulations have been superimposed. Additionally, Wyle researchers classified each collision cause as probably stressor related, possibly stressor related, or not likely to be stressor related. These classifications are indicated in each of the four figures.

As can be seen from an examination of the figures, no significant relationship appears to exist between the occurrence of particular collision causes and stressor (or stressor combination) levels. This could be due to the sparcity of stressor data available. Thus, it was decided to compare the stressor levels with causes combined according to the stressor-related categories indicated in the figures. The results of this analysis follows.

Fatigue vs Cause

Relationship of causes to any stressors	Fatigue High	Fatigue Low	Sum	Total Causes
Probably	4	5	9	30
Possibly	5	3	8	48
Unlikely	5	8	13	88
Sum	14	16	30	166

Collapsed Table For Computing Significance

	High	Low	
Possibly + Probably	9	8	17
Unlikely	5	8	13
	14	16	30

Fisher; p>80%

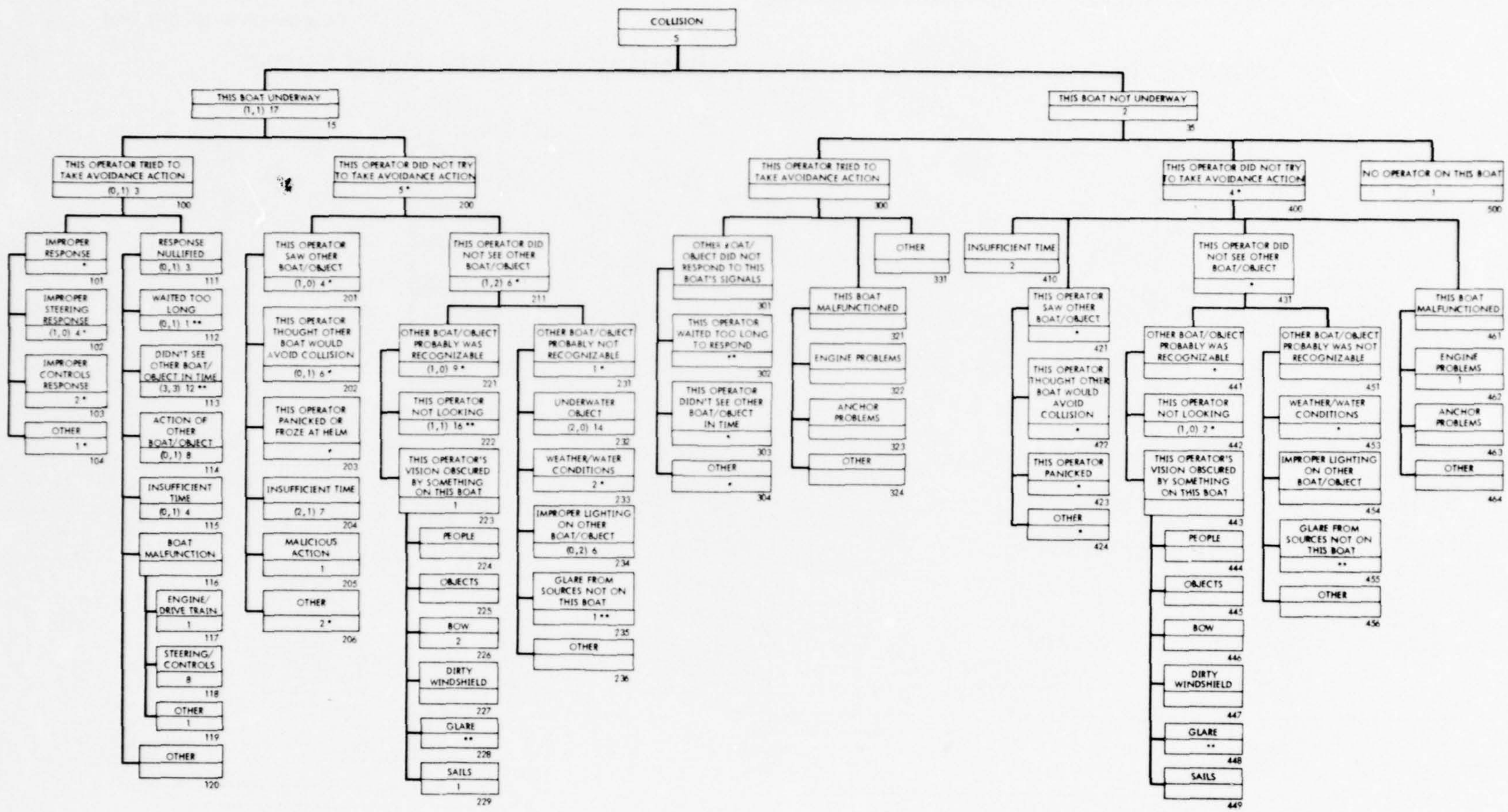


FIGURE 3-20. CAUSES IN ALL COLLISIONS AS A FUNCTION OF FATIGUE LEVELS

* Possibly stressor-related

** Probably stressor-related

Parenthetical frequencies indicate instances of high fatigue vs low fatigue.

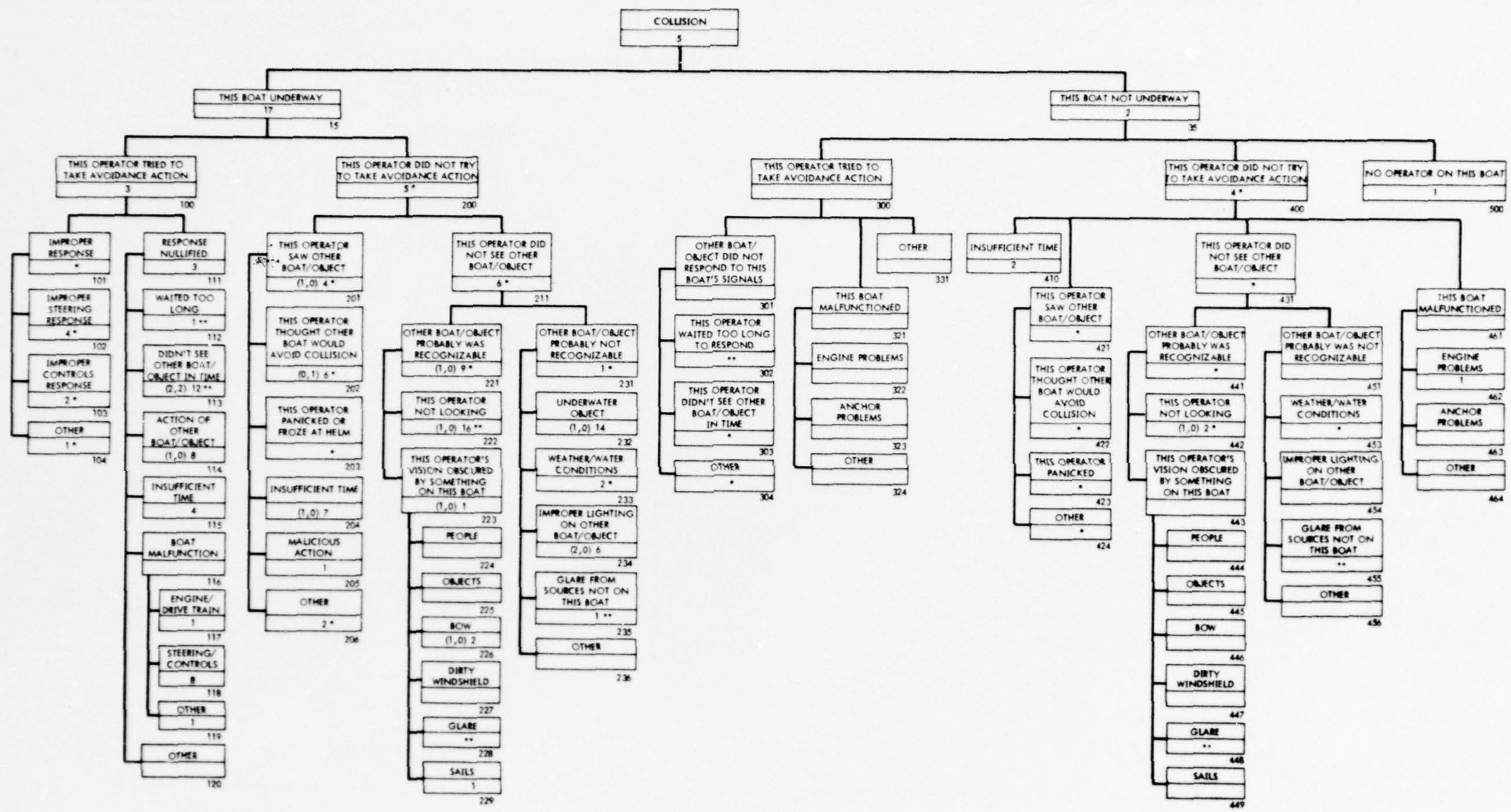


FIGURE 3-21. CAUSES IN ALL COLLISIONS AS A FUNCTION OF NOISE AND GLARE LEVELS

* Possibly stressor-related

** Probably stressor-related

Parenthetical frequencies indicate instances of high noise and high glare vs low noise and low glare.

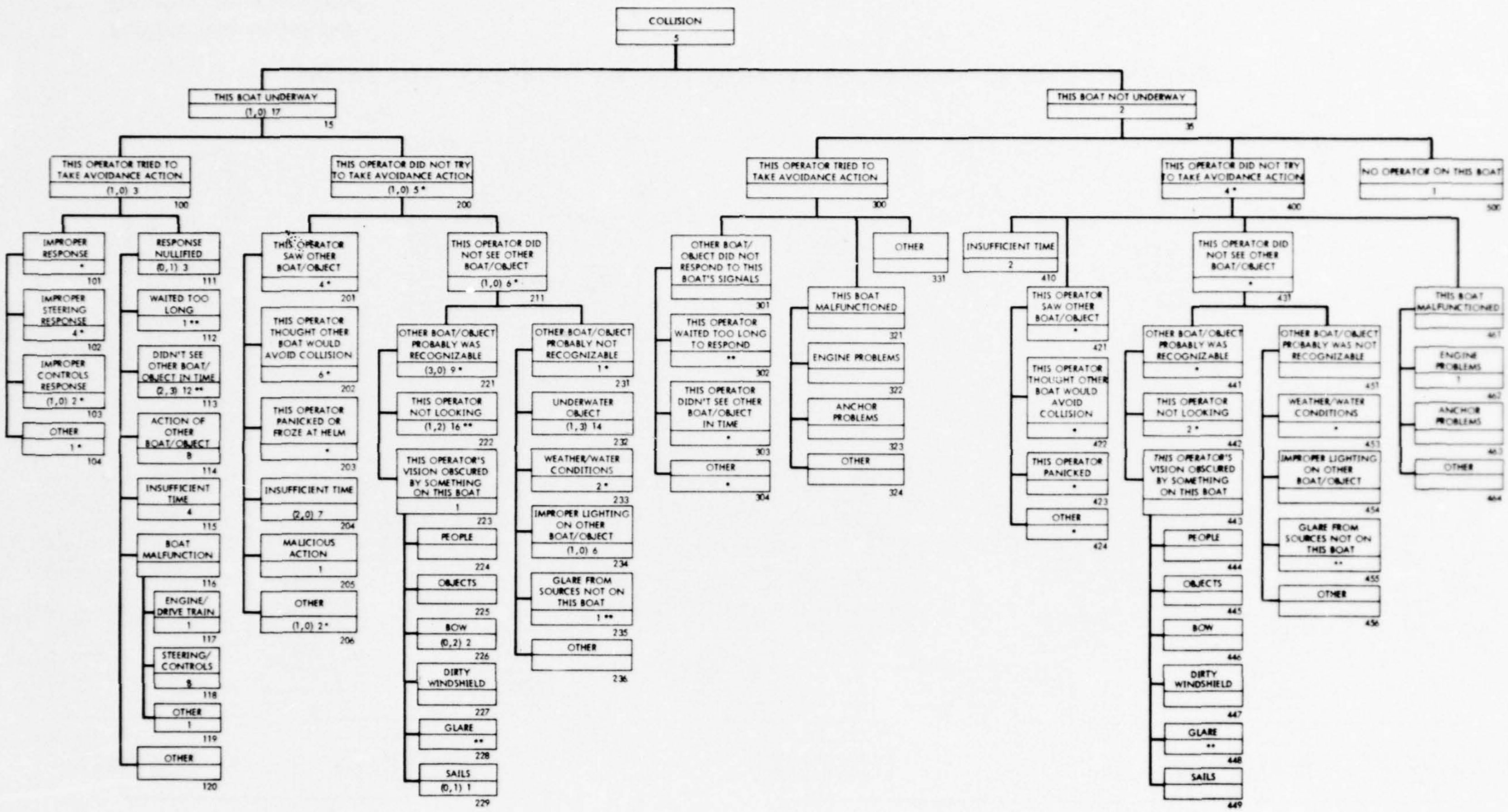


FIGURE 3-22. CAUSES IN ALL COLLISIONS AS A FUNCTION OF DRINKING

* Possibly stressor-related
** Probably stressor-related

Parenthetical frequencies indicate drinking vs non-drinking operators.

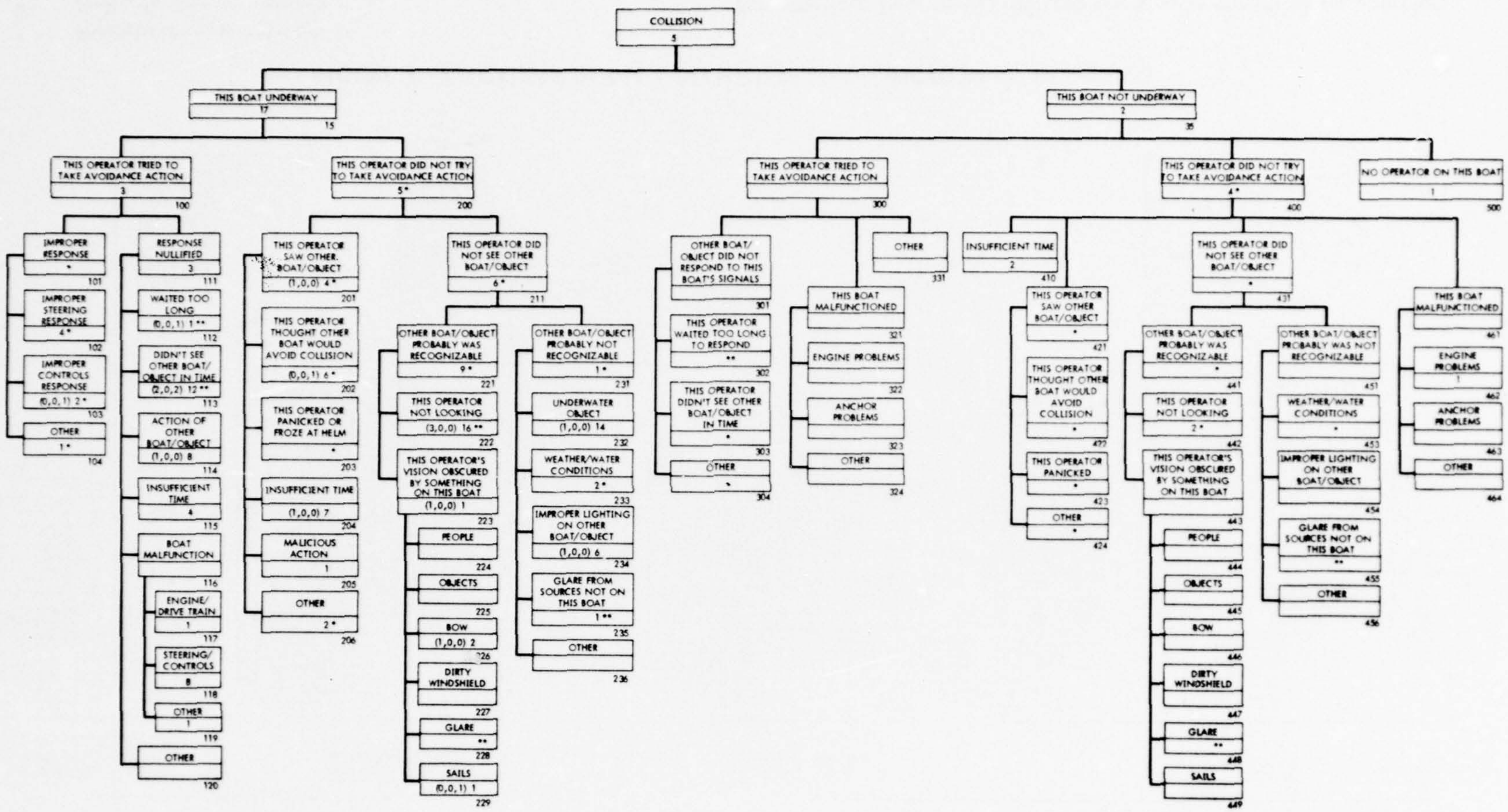


FIGURE 3-23. CAUSES IN ALL COLLISIONS AS A FUNCTION OF SHOCK AND NOISE

* Possibly stressor-related

** Probably stressor-related

Parenthetical frequencies indicate instances of high shock and high noise vs low shock and high noise vs low shock and low noise.

Noise And Glare vs Cause

Relationship of causes to any stressors	Noise And Glare High	Low	Sum	Total Causes
Probably	3	2	5	30
Possibly	3	1	4	48
Unlikely	7	0	7	88
Sum	13	3	16	166

Collapsed Table For Computing Significance

	High	Low	
Possibly + Probably	6	3	9
Unlikely	7	0	7
	13	3	16

Fisher; p = 30%

Drinking vs Cause

Relationship of causes to any stressors	Drinking Yes	No	Sum	Total Causes
Probably	3	5	8	30
Possibly	7	0	7	48
Unlikely	6	7	13	88
Sum	16	12	28	166

Collapsed Table For Computing Significance

	Yes	No	
Possibly + Probably	10	5	15
Unlikely	6	7	13
	16	12	28

$X^2 = 0.313$; p= 57%

Shock And Noise vs Cause

Relationship of causes to any stressors	High shock High Noise	Low shock High noise	Low shock Low noise	Sum	Total Causes
Probably	5	0	3	8	30
Possibly	1	0	2	3	48
Unlikely	6	0	1	7	88
Sum	12	0	6	18	166

Collapsed And Abridged Table For Computing Significance

	High shock High noise	Low Shock Low noise	
Possibly + Probably	6	5	11
Unlikely	6	1	7
	12	6	18

Fisher; p = 40%

As can be seen, no results significant at the 5% level were achieved.

3.6 Results of Data Analysis — Stressors

The analysis showed that the usual accident reports do not furnish sufficient data on stressors. This may account for the lack of statistically significant results in tests on stressors vs. collision causes, or it may be that operator stressors do not play as important a role in collision causes as first believed. Another possibility is that stressors affect collision causes but in an unexpected manner, so that our classification of collision causes as probably, possibly, or unlikely to be stressor related is erroneous. The only way to determine which conclusion is correct is to continue, as the Coast Guard is doing, in-depth collision investigations on which stressor data is specifically looked for.

4.0 BOAT DESIGN PARAMETERS WHICH IMPAIR OPERATOR PERFORMANCE AND MAY CONTRIBUTE TO COLLISIONS

4.1 Introduction

In Task III of Phase I of the collision research effort (Reference 1), Wyle measured and recorded certain boat related parameters and related them to human performance capabilities in an effort to determine if the parameters were at a level that could cause operator performance degradation. Those parameters are listed below along with a short synopsis of the results of the Phase I effort.

- Visibility

  Visibility distances of 270 underway boats were measured; 10% of the operators couldn't see the water in front of them.
- Visibility problems that were found to be severe included:
  - glare,
  - windshield cleaning methodology,
  - tinted windshields,
  - objects forward of operators,
  - people forward of operators, and
  - the sailboat visibility problem area.
- Control forces - steering wheel

  Measured wheel forces exceeded strength capabilities of a portion of the boat user population.
- Control forces - shift and throttle levers

  Measured lever forces exceeded strength capabilities of a portion of the boat user population.
- Noise

  Two hundred and eleven sound level measurements made from the operators position of boats under power were analyzed. A significant number of the data points fell within the range of sound levels that mask speech communication, cause temporary and permanent hearing losses, and may cause other physiological problems.

Most startling were the results of the referenced wind noise experiments. Sound levels from wind alone measured over 100 dBA inside the human ear at 40 mph (64.4 kph).

- Shock and vibration

  Vibration was measured in the "normal" boating environment. Frequencies were found to fall within the range of resonance of the head. Amplitudes fell within the "unpleasant" range.

- *Control station design*

  Control stations of twelve runabouts, three center console boats, and two cruisers were measured and evaluated against known human engineering standards. None of the boats met the standards. Some serious problems were defined.

Each parameter has been revisited briefly. The results of the Phase I research effort have been summarized and compared to the results of the data analysis. Common problems are listed and discussed.

4.2 Visibility Problems

4.2.1 Background

During Phase I of the Collision Research effort, several aspects of the problem of being able to see where one is going while operating a boat were investigated. The results of those efforts are summarized below. The detailed visibility problem analysis may be found in Reference 1.

Two hundred and seventy boats were photographed in profile as they traversed a waterway. The photographs were used to measure the distance forward of the boat that the helmsman could see the water. Results showed that half of the boats didn't meet the minimum standards set by ABYC which state that the helmsman must be able to see the water 100 ft (30.5 m) forward of the bow. Most astonishing was the fact that 10% of the drivers of the boats photographed couldn't see the horizon forward of the boat at all because it was obscured by the bow, cabin top, objects, or people. Repeat...10% of the drivers couldn't see where they were going.

The photographic study reinforced the theory that there is a visibility problem with small pleasure boats. Other visibility related problem areas were researched and are listed below.

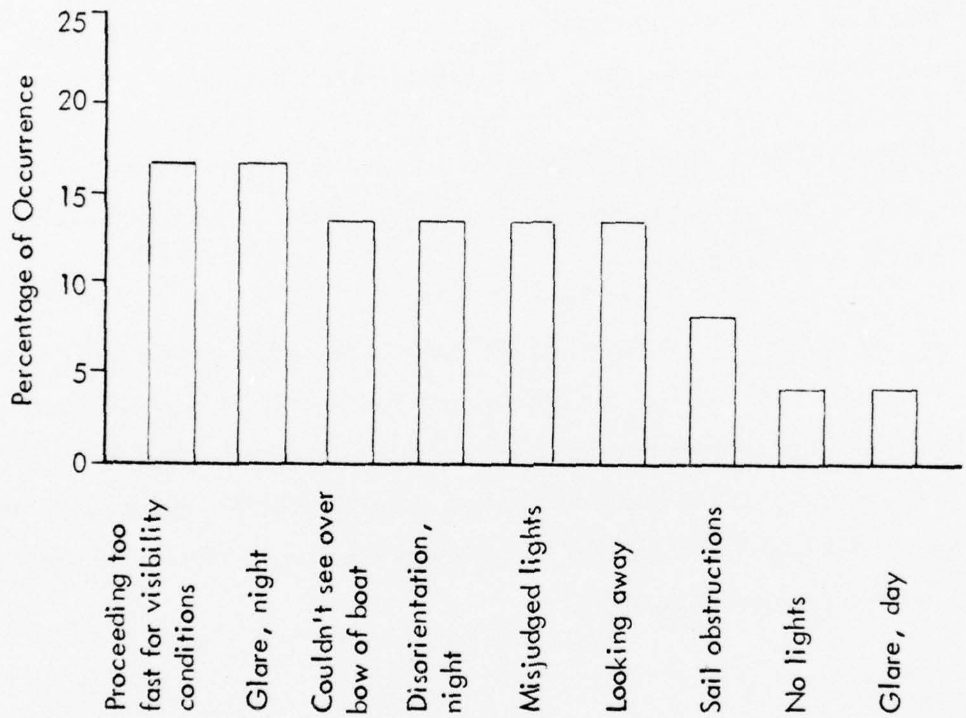
Windshields - Visibility problems occur from the degredation of the operator's ability to detect visual targets through the windshield due to glare, reflections, foreign matter on windshield surfaces and tinting. The automotive and aircraft industries have standards to reduce the above mentioned problem areas. The boating industry doesn't.

Obstructions - Visibility problems from pillars, posts, windshield frames and wipers, objects, people, canvas tops and sides, sails, and from the forward portion of the boats were documented and thoroughly discussed.

Operators Out of Position - A survey of 270 boats in operation showed that 1/3 of the operators were standing, kneeling, etc., in order to get their eye point high enough to see adequately. Analysis of the photographs showed that standing runabout operators could see the water 141 ft (43 m) closer to the boat when compared to the visibility distance of those sitting beside them. Although this is basically a visibility problem, it affects the operator's ability to reach and manipulate his controls.

4.2.2 Visibility Problems — 1975 In-Depth Investigations

Visibility problems were identified in all of the collisions that were investigated in-depth in 1975. Those visibility problems are summarized graphically as follow. The percentage of occurrences are based on the number of boats involved.



It is interesting to note the the visibility problems are spread almost evenly among many rather diverse causes, many of which are night oriented because of six of the ten collisions happened at night. No comments will be made on the visibility problems shown in the table, because they are identical to those identified in the research efforts discussed later in this section. The point to be made is that the same problems are being identified over and over, in the in-depth investigations, telephone interviews, data analysis, and direct observation technique.

4.2.3 Visibility Problems — 1975 Data Analysis

One hundred and five collisions involving 166 boats were coded for cause and stressors. To identify visibility related problems, Wyle researchers divided the cause blocks into three groups: causes that were probably visibility problem related, causes that were possibly visibility problem related, and causes which were not likely to be related to a visibility problem.

Figure 4-1 is a reproduction of Figure 3-4 showing all collision causes, with visibility related causes identified. The following table summarizes the data in this figure.

BOATS BY RELATIONSHIP OF COLLISION CAUSE TO VISIBILITY

	Boat Underway		Boat Not Underway		Total	
Unlikely	76	(51%)[1]	4	(33%)[2]	80	(50%)[3]
Possibly	53	(36%)	8	(67%)	61	(38%)
Probably	20	(13%)	0	(0%)	20	(12%)
Total: Possibly + Probably	73	(49%)	8	(67%)	81	(50%)

[1] Percent of 149 boats underway

[2] Percent of 12 boats not underway

[3] Percent of 161 boats for which some cause was coded

As can be seen from the table, about half of the boats underway and two-thirds of the boats not underway had collision causes attributable to them which were at least possibly visibility related. Also, twelve percent of the collision-involved boats were coded with causes which were probably visibility related.

An alternative way of summarizing visibility related causes is by accident rather than by boat. Thus, for two-boat collisions there would be two causes. The next table follows this scheme each data point representing one collision. The row across the top gives the visibility relationship of the cause coded for one of the boats and the column at the left gives the relationship of the cause coded for the second boat. Additionally, the number of fatalities corresponding to the collisions are also presented.

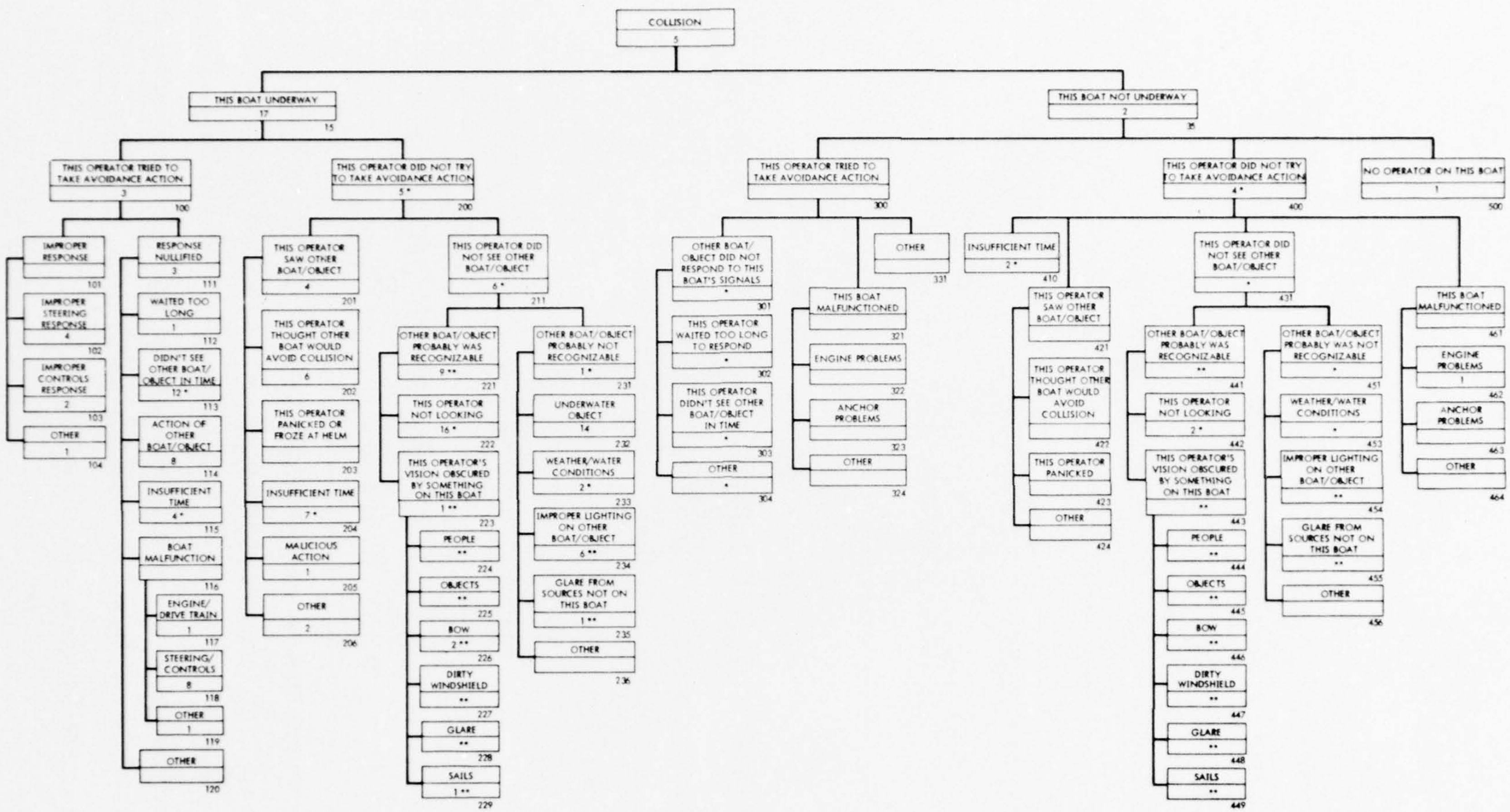


FIGURE 4-1. CAUSES IN ALL COLLISIONS RELATED TO VISIBILITY

* * Probably vision related

* Possibly vision related

(others unlikely to be vision related)

COLLISIONS/FATALITIES BY RELATIONSHIP OF CAUSES TO VISIBILITY

	Two-Boat Collisions[1]			One-Boat Collisions[2]
	Unlikely	Possibly	Probably	
Unlikely	15/7	19/7	8/3	28/9
Possibly	---	10/6	9/7	12/2
Probably	---	---	0/0	3/2

[1] In two-boat collisions where one of the causes was coded as unknown, the unknown cause was classified as "unlikely."

[2] One grounding with unknown cause not included.

If one adopts the admittedly optimistic viewpoint that in the case of two-boat collisions, removal of either collision cause would prevent the collision, then the next table is useful. In it we classify the collisions in the preceeding table according to the likelihood that either boat in two-boat collisions had a visibility-related cause. The method used in this classification is described in Appendix C.

COLLISIONS AND FATALITIES BY RELATIONSHIP OF CAUSES TO VISIBILITY

	Collisions	Fatalities
Not Likely	43 (41%)	16 (37%)
Possibly	31 (30%)	9 (21%)
Probably	30 (29%)	18 (42%)
Total	104 (100%)	43 (100%)

This table even more dramatically shows the role visibility plays in collisions. In our sample, 42% of the fatalities were in collisions which had causes which were probably visibility related.

4.2.4 Nighttime Collisions — 1974 Data Analysis Summary

Collisions that occurred at night were studied in Task II of the Phase I collision research effort (Reference 1), in a separate Coast Guard sponsored survey (Reference 3), and in the current data analysis effort in addition to the six nighttime collisions investigated in-depth in 1975. Results of the three studies appear below.

The 1975 Data Analysis effort of 105 collisions involving 166 boats showed that 35% of the accidents occurred at night. A study of sixty-nine collisions called into Wyle through the WATS accident reporting system in 1974 revealed that twenty-one collisions or 30% of the sixty-nine collisions happened when it was dark. Assuming that the number of boats on the water at night is less than 30% of the number of boats on the water during the day, the nighttime collision rate is higher than the daytime rate.

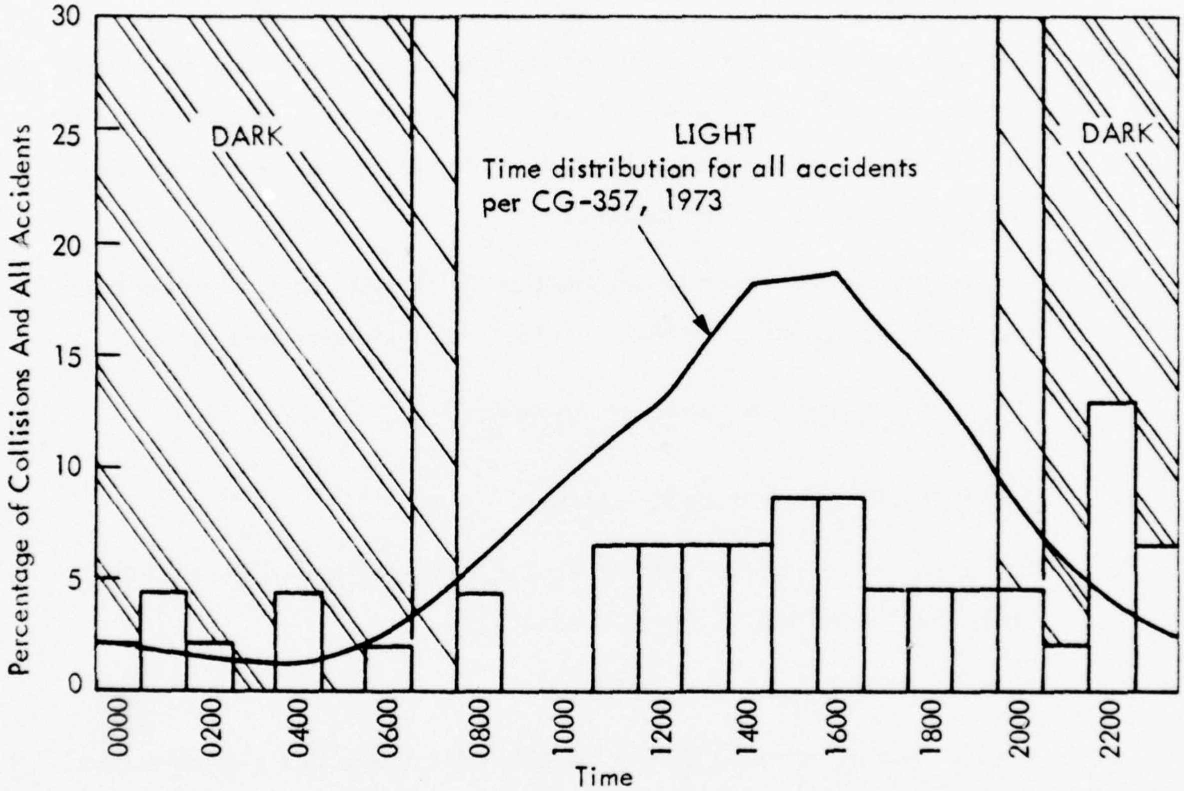
During the 1974 collision research erfort, the assumption was made that boating accidents tend to parallel boating activity.

A test of the theory that the nighttime collision rate is higher than the daytime rate was devised during the 1974 collision research effort. The assumption was made that boating accidents tend to parallel boating activity. A curve of the time distributions of all boating accidents was superimposed over a hystogram of the time distribution of collisions reported in the 1974 Summer Study, Figure 4-2. Note that the data tend to support the theory because the hystograms break through the curve only at night.

The causes of the twenty-one nighttime collisions were predominantly visibility oriented. In fact, thirteen of the twenty-one collisions were attributed to visibility related causes as detailed below in order of their frequency of occurrences.

LIGHTING PROBLEMS CAUSING COLLISION

1. The operator of a homemade houseboat kept the 360° white light out because it ruined his visibility. A speed boat hit him from the rear. The speed boat



(Bars Indicate Percentage of Collisions At That Time in 1974 Summer Study)

Figure 4-2. Accident Rate vs. Collision Rate

driver was sitting on the back of the seat so he could look over the windshield because his own 360° white light created too much glare on the glass.

2. A tug boat hit a runabout that was adrift without any navigation lights. The operator of the runabout had been drinking.

3. A boat anchored with no anchor light was hit by another boat.

4. Two boats, each going about 30 mph (48 kph) hit head on. One had illegal lighting (no 360° white light) and the other's white light was obscured in the forward sector by passengers. In addition, the shorelines were filled with bright lights, many of them colored.

5. Two commercial fishermen in two small boats hit each other. Neither boat had navigation lights. The fishermen said they had never used lights.

SPEEDING RELATED TO VISIBILITY

6. Boat going 50 mph (80 kph) hit a bridge.

7. Boat traveling at about 30 mph (48 kph) rounded a bend and hit an unlighted barge that had drifted across the channel.

8. Boat hit unlighted concrete platform.

9. A boat traveling at about 35 mph (56 kph) ran into the side of another boat. A well lighted shoreline was in the background.

DISORIENTATION AND NAVIGATIONAL ERRORS

10. Operator mistook jetty intermediate lights with those at the end of the jetty. He ran the boat up onto the jetty.

11. Boat in unfamiliar water traveling at about 25 mph (40 kph) with no chart hit an unlighted buoy and sank.

12. Operator tried to take a short cut between channel entrance buoy and breakwall. The boat hit the wall and sank.

Lighting related causes were most prominent and directly accounted for 38% of the nighttime visibility oriented collisions. Within the lighting related cause group four of the five collisions (1, 2, 3 and 5) occurred because one of the boats had no lights while in the one remaining case (4) the lights were illegal. For example, in one of the cases the 360° white light was illegal because it was mounted inside the cockpit area of a houseboat, and, therefore, it wasn't visible through 360°. The owner never turned it on because it made such a glare on the windshield that he couldn't see where he was going.

The operator of the speedboat that hit him had the same problem. The 360° white light gave so much glare that he couldn't see through it so he sat on the back of the seat and looked over it. By sitting on the seat, the operator obscured his own 360° white light.

In at least two of the cases (4 and 9) the well lighted shoreline contributed to the fact that the operator of one boat didn't see the boat or object that he hit. This could account for the peak in the collision occurrences around 2200. There is a good probability that lighted shorelines obscured the boat or object that the hittor hit in some of the other cases. However, the information didn't surface during the telephone screening process.

It appeared as if the combinations of dark nights, bright colored lights on the shoreline and high speed made it very difficult to see the tiny combination red/green navigation light of another boat. To compound the problem, an approaching boat on a collision course shows no relative motion, hence its navigation light appears to be motionless, even though the boat could be travelling at a high speed.

All four of the speeding related collisions also involved lighting in that the collision probably wouldn't have occurred if the object that was hit had been well lighted. However, they were classified as speed related since it was felt that the "hittors" were travelling too fast for conditions, and the collisions didn't involve illegal or lack of proper navigation lights.

It was interesting to note that the three disorientation and navigational error collisions also related to lights in that two of them involved lighted navigational aids, while one involved an unlighted buoy.

In summary, within the thirteen visibility oriented nighttime collisions studied during Phase I of the Collision Research effort, lighting (or lack of lighting) was directly related to the cause of 38%, but was a contributing factor in all the visibility related nighttime collisions.

4.2.5 Nighttime Collisions — 1975 In-Depth Investigations

Six of the ten collisions investigated in-depth in 1975 occurred at night.

A synopsis of each appears below:

Collision 1 - Five people picnicked, waterskied, and drank on the bank of a river for most of the afternoon. It was dark when they decided to go home. Just after leaving the picnic site on their way to the launch ramp, two of the three boats collided. Two people were thrown into the water; one died. The hittor couldn't see over the bow because his boat was at "hump" speed. The hittee's boat had no lights.

Collision 2 - A runabout hit a bridge abutment at night. The lone accupant was standing beside the helm as he approached the bridge. When a large cabin cruiser appeared to block the entire opening, the driver made a sharp right hand turn. The boat swerved, he lost his balance, fell to his knees, and was knocked unconscious when the boat hit the bridge. He was standing because he had to look over the windshield to see where he was going. The stern light threw such a glare that when it was on he couldn't see through the windshield.

Collision 3 - Just before dawn, two men were going down a river in a runabout. They hit an unlighted bridge abutment. One man was seriously injured. Their visibility distance was less than the stopping distance of their boat at the speed that they were going.

Collision 4 - A family was on their way home from an evening cruise when their 31 ft (9.45 m) cruiser ran up onto a lighted breakwater. No one was injured. The operator was disoriented. He thought he was about 100 yd (91.44 m) to the right of his actual position. The mass of shore lights that obscured the lighted aids to navigation was thought to be the cause of his disorientation.

Collision 6 - A 23 ft (7.01 m) boat ran up onto a lighted breakwall late at night. The operator made a navigational error while attempting to enter a harbor. He was disoriented and misinterpreted the lighted aids to navigation.

Collision 7 - Just before dawn, a 97 ft (29.57 m) ketch operating under motor alone went aground on a sandbar near a small inlet. The operator made an error in identifying the lighted main channel buoy, and, therefore, in his boat's position.

The causes of all of the 1975 in-depth nighttime collisions were lighting related. Three were caused because the operator mistakenly identified his position with respect to charted and lighted navigational aids. Glare from shore lights and/or stern lights was identified in two collisions, three boats were going too fast for visibility conditions, and one had no lights.

4.2.6 Nighttime Collisions — Telephone Interviews

Wyle performed a telephone interview study in 1975 wherein the victims of 150 nighttime boating collisions were contacted and were asked to answer questions concerning their accident (Reference 3). Results showed that:

- Nearly 2/3 of the collisions were on lakes
- There were no dominant trends in length, type, or manufacturer of the boats involved, although 38% of them were 15 ft (4.57 m) to 17 ft (5.18 m) long
- Forty-two percent of the nighttime collisions occurred in the first hour of operation
- Sixty-one percent of the accidents happened between 2000 and 2300, typically in clear weather
- Seventy-one percent of those who saw something before the collision, saw the other boat before seeing its lights, partially because 42% said the other boat's lights weren't on
- The water was nearly always calm, and PFDs (personal flotation devices) were usually not being worn

- Thirteen percent of the boaters surveyed reported trouble with shore lights hiding the presence of another boat or confusing its position

- The estimated angle at which one loses sight of the red or green bow light ranged widely, with 73% of the answers between 90° and 180°. Twenty-three percent didn't have a strong enough feeling to even give an estimate

- Only 42% of the boaters interviewed identified their red light as being on the left side of the boat. Thirty-two percent said "right," 25% didn't know, and one percent had no red light.

- Forty-one percent of the boaters said that their forward facing white light adversely affected their ability to see at night

- Nearly half of the boating accidents occurred when one or both of the boats had lights that were not functioning properly if at all, still more had functioning lights that were not on

- Eighty-three percent of those surveyed said they could tell which way another boat was heading from its lights at least sometimes

- Forty-five percent said the red/green lights were easier to see if separated, 20% said they were more difficult to see if separated, and 35% expressed no preference. Similarly, 43% said the red light was easier to see, 20% said the green, and 37% expressed no preference.

The study produced the following conclusions:

- Make the stern light something other than plain white (perhaps flashing and/or amber). This would increase the chances of it being detected and make it easier to distinguish from shore lights.

- Make the red and green lights more visible. Most boaters felt that these lights, when visible, offered the most help as to the presence of another boat and its course.

- Make efforts to get the lights off the water (to be seen above waves and obstacles), but low enough as to be associated with a boat and not the horizon.

- The fact that 83% of the boaters could tell which way another boat was heading by his lights, but only 42% could identify their red light as being on the left side of their boat, indicates that they are sensitive to color vs. white, and not "red" or "green" per se. Boaters appear to be much more interested in knowing front vs. back of a boat they see than left vs. right.

- Many of the problems could be handled by education. Among these are: misleading lighting arrangements (such as one boat which had all red lights), misinterpretation or no knowledge of the "rules of the road," inexperience, lack of attention or carelessness, speeding, overloading or going too slow (bow up), and not turning on the lights after dark.

- Finally, many boaters would like to see something done about the glare problem from the 360° stern light (screen, shield, etc.).

The data analysis effort of the 105 collisions reported over the WATS accident reporting system during 1975 produced similar conclusions. Results of both day and night visibility problems that were identified are combined in the following research summary.

4.2.7 Daytime vs. Nighttime Collisions — 1975 Data Analysis

The causes of nighttime collisions were compared to causes of daytime collisions. Figures 4-3, 4-4, 4-5, and 4-6 summarize the data. We are particularly interested in any differences in the relative frequencies of occurrence of causes in daytime and nighttime collisions. Thus, just as we did for non-fatal vs. fatal collisions, we examine the cause percentages and apply statistical tests to those cause frequencies which appear likely to have significantly different percentages in daytime and nighttime collisions. The same tests will be used as were used in testing non-fatal vs. fatal collisions. The reader is referred to Section 3.0 and Appendix B for a description of these tests.

An examination of Figures 4-5 and 4-6 suggest that the following causes might show significantly different percentages of occurrence in daytime and nighttime collisions.

Cause	113.	Didn't see other boat/object in time
	114.	Action of other boat/object
	115.	Insufficient time
	118.	Steering/controls malfunction
	204.	Insufficient time
	222.	This operator not looking
	100.	This operator tried to take avoidance action
	101.	Improper response (cumulative)
	111.	Response nullified (cumulative)
	116.	Boat malfunction (cumulative)
	200.	This operator did not try to take avoidance action (cumulative)
	201.	This operator saw other boat/object (cumulative)
	211.	This operator did not see other boat/object (cumulative)
	221.	Other boat/object probably was recognizable (cumulative)
	223.	This operator's vision obscured by something on this boat (cumulative)
	231.	Other boat/object probably not recognizable (cumulative)

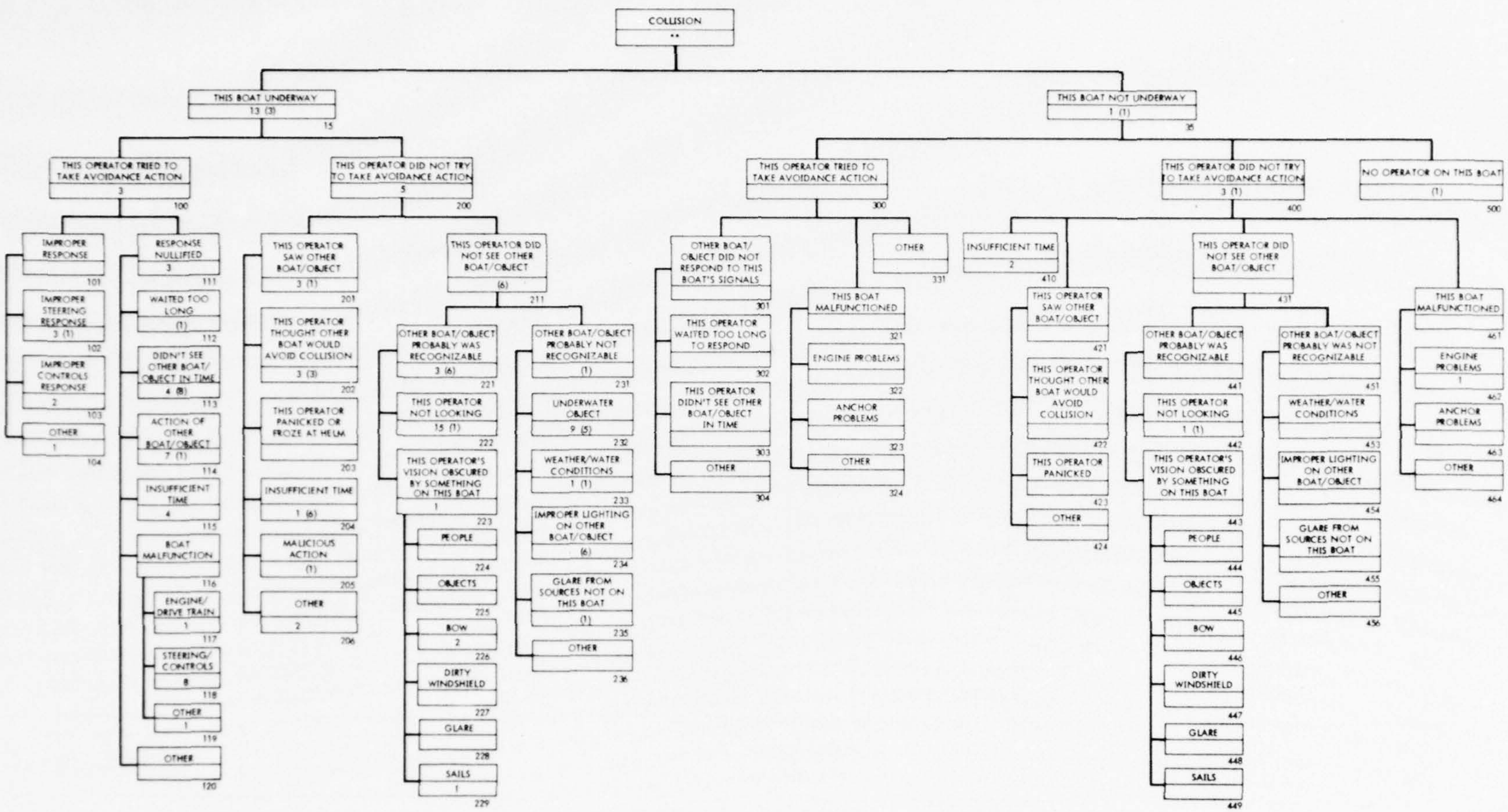


FIGURE 4-3. CAUSES IN DAYTIME AND NIGHTTIME COLLISIONS*

* Nighttime collision cause totals shown in parentheses, ( ); unknowns excluded.
** Category omitted - unnecessary for analyses performed and data insufficient.

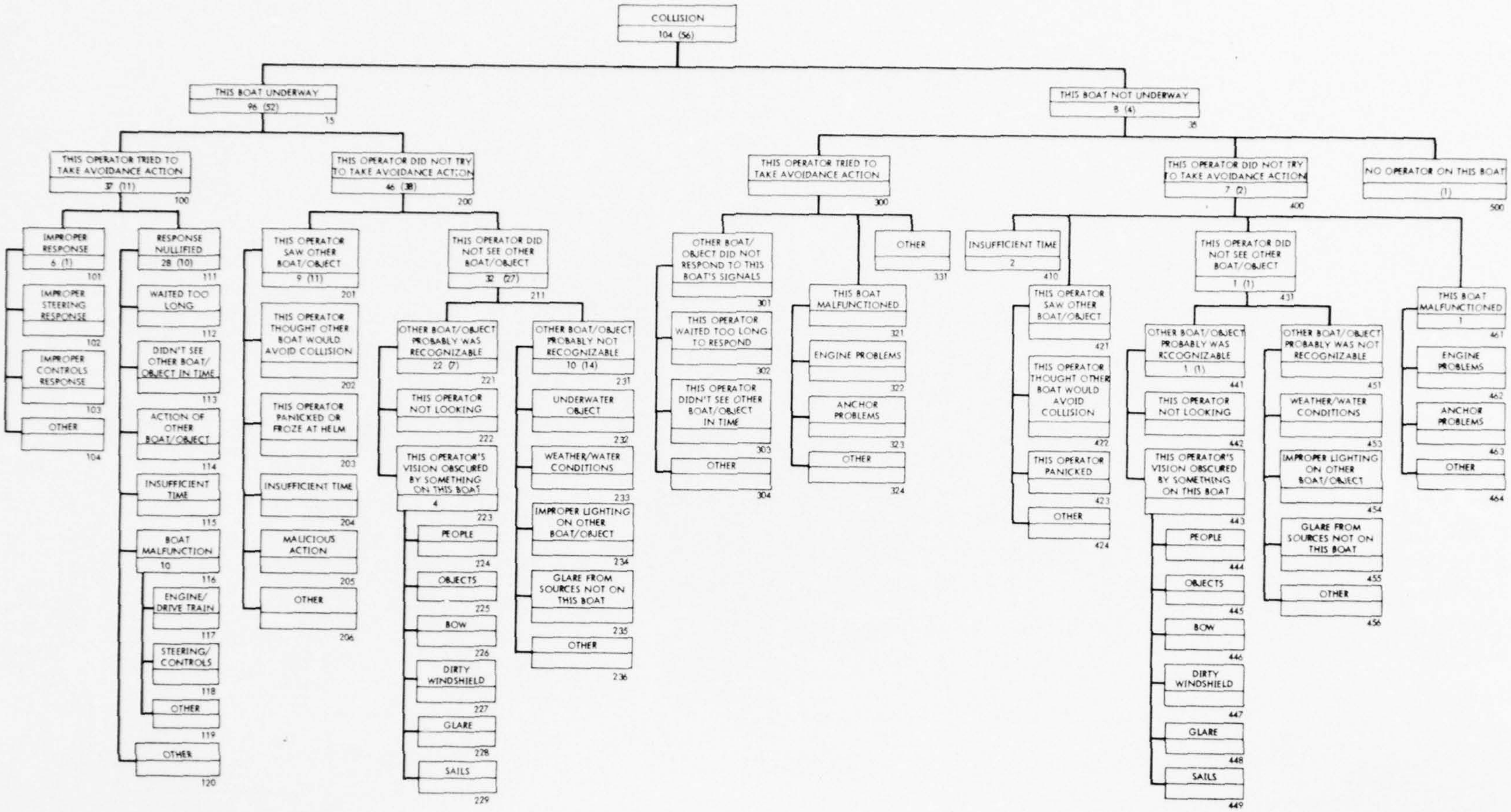


FIGURE 4-4. CUMULATIVE COLLISION CAUSES IN DAYTIME AND NIGHTTIME COLLISIONS *

* Nighttime collision cause totals shown in parentheses, ( ); unknowns excluded.

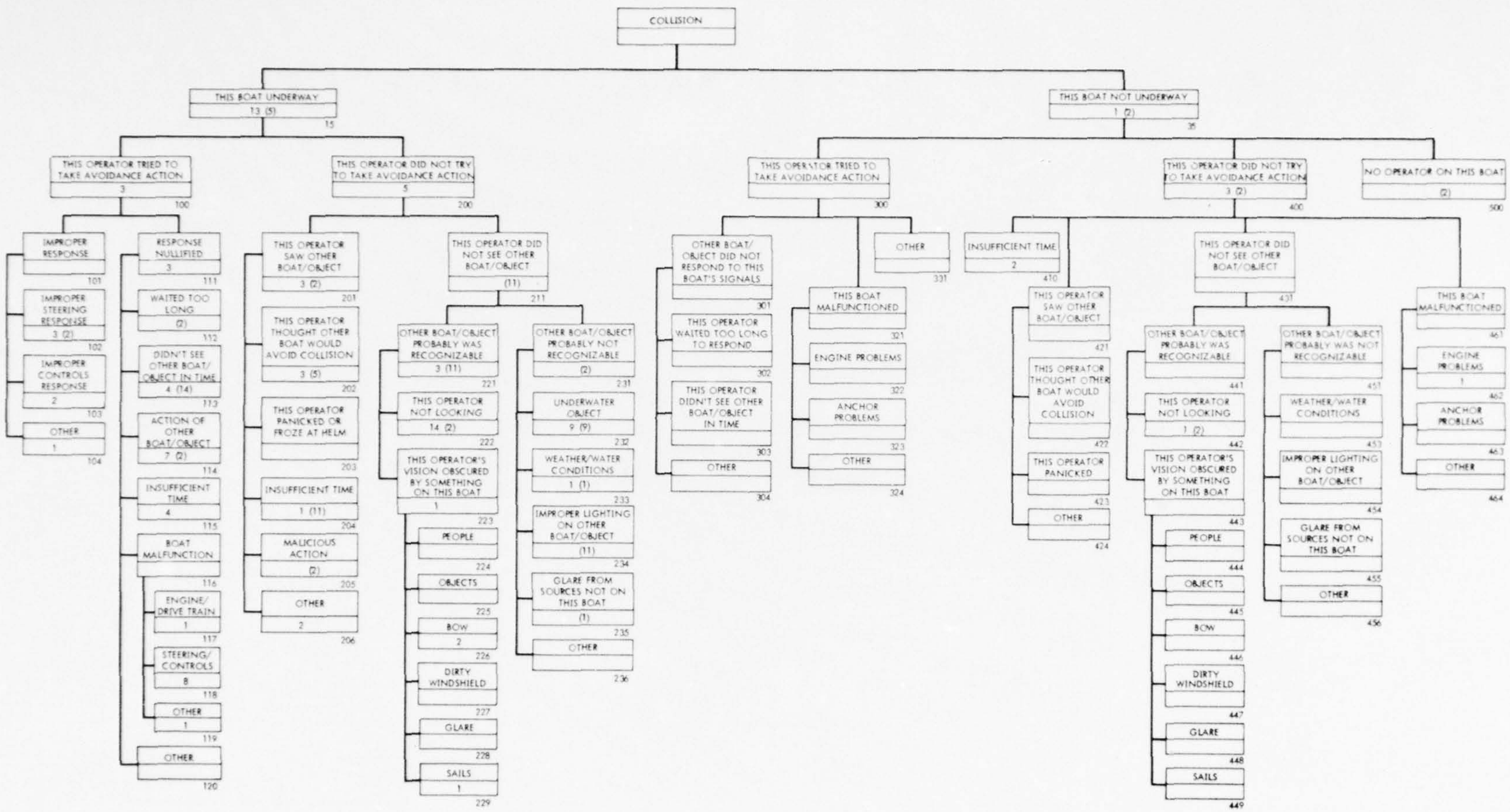


FIGURE 4-5. CAUSE PERCENTAGES IN DAYTIME AND NIGHTTIME COLLISIONS*

* Nighttime collision cause totals shown in parentheses, ( ); unknowns excluded.

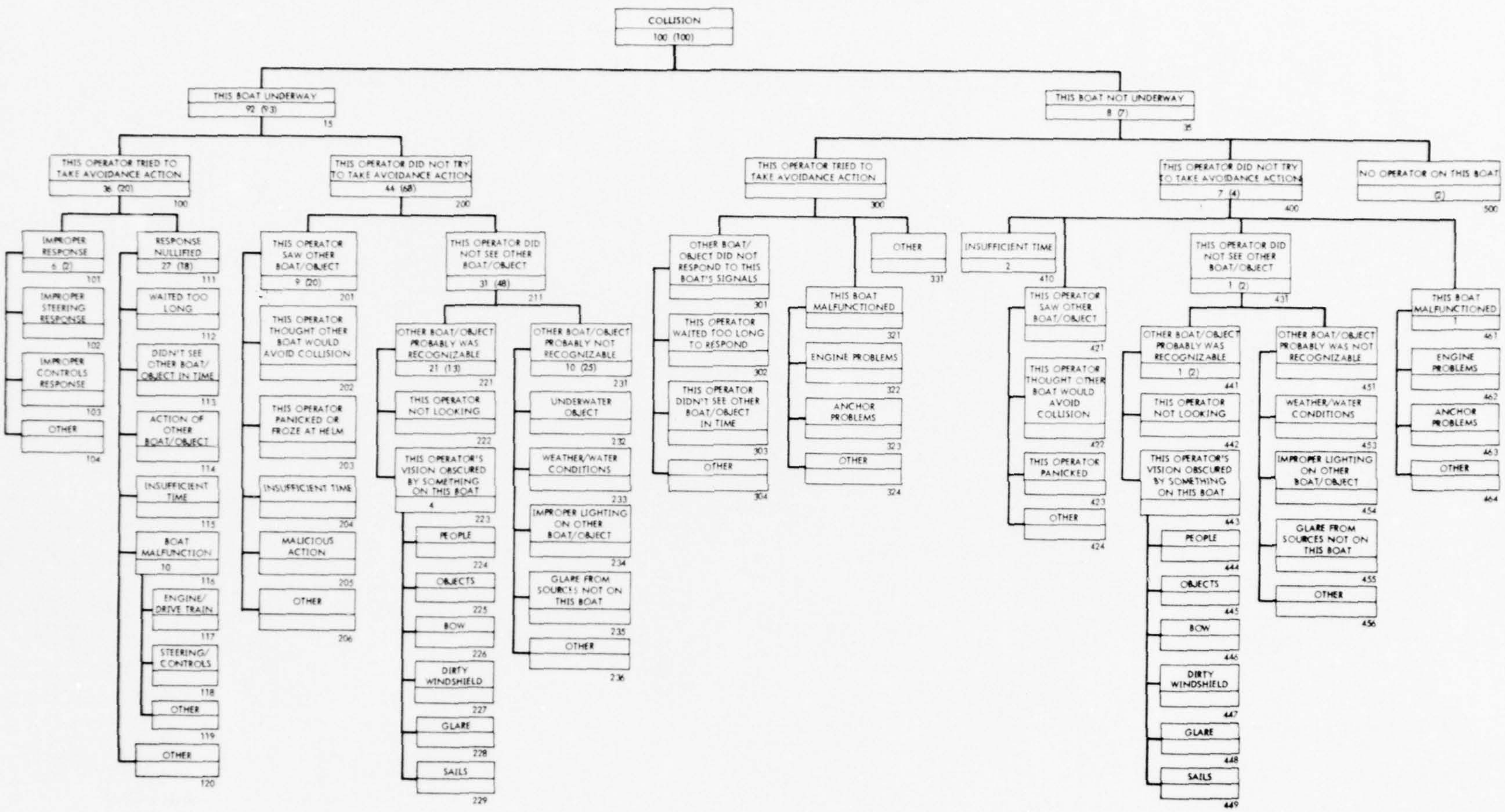


FIGURE 4-6. CUMULATIVE CAUSE PERCENTAGES IN DAYTIME AND NIGHTTIME COLLISIONS*

* Nighttime collision cause percentages shown in parentheses, ( ); unknowns excluded.

Following are the statistical tests of these cause frequencies. In each instance, the initial contingency table is shown, the type of test is indicated and the approximate significance level of the test result is given.

Cause 113.

First Test

4	100	104
8	48	56
12	148	160

Fisher; p = 4.2%

Second Test

4	73	77
8	41	49
12	114	126

Fisher; p = 8.1%

Cause 114.

First Test

7	97	104
1	55	56
8	152	160

Fisher; p>27%

Second Test

7	70	77
1	48	49
8	118	126

Fisher; p = 22.2%

Cause 115.

First Test

4	100	104
0	56	56
4	156	160

Fisher; p = 35%

Second Test

Not computed due to non-significant result on first test

Cause 118.

First Test

8	96	104
0	56	56
8	152	160

Fisher; p = 5.8%

Second Test

8	69	77
0	49	49
8	118	126

Fisher; p = 3.4%

Cause 204.

First Test

1	103	104
6	50	56
7	153	160

Fisher; p = 1.5%

Second Test

1	74	75
6	42	48
7	116	123

Fisher; p = 2.8%

Cause 222.

First Test

15	89	104
1	55	56
16	144	160

Fisher; p = 1.4%

Second Test

15	60	75
1	40	41
16	100	116

Fisher; p = 1.2%

Cause 100.
(cumulative)

First Test

37	67	104
11	45	56
48	112	160

$\chi^2 = 3.67$; $5\% < p < 10\%$

Second Test

37	46	83
11	38	49
48	84	132

$\chi^2 = 5.60$; $1\% < p < 2.5\%$

Cause 101
(cumulative)

First Test

6	98	104
1	55	56
7	153	160

Fisher; $p > 36\%$

Second Test

Not computed due
to non-significant
result on first test

Cause 111.
(cumulative)

First Test

28	76	104
10	46	56
38	122	160

$\chi^2 = 1.19$; $20\% < p < 30\%$

Second Test

Not computed due
to non-significant
result on first test

Cause 116.
(cumulative)

First Test

10	94	104
0	56	56
10	150	160

Fisher; p = 23%

Second Test

10	67	77
0	49	49
10	116	126

Fisher; p = 1.1%

Cause 200. (cumulative)

First Test

46	58	104
38	18	56
84	76	160

$\chi^2 = 4.04$; $2.5\% < p < 5\%$

Second Test

46	37	83
38	11	49
84	48	132

$\chi^2 = 5.60$; $1\% < p < 2.5\%$

Cause 201. (cumulative)

First Test

9	95	104
11	45	56
20	140	160

$\chi^2 = 3.08$; $5\% < p < 10\%$

Second Test

9	68	78
11	38	49
20	107	127

$\chi^2 = 1.94$; $10\% < p < 20\%$

Cause 211. (cumulative)

First Test

32	72	104
27	29	56
59	101	160

$\chi^2 = 4.04$; $2.5\% < p < 5\%$

Second Test

32	46	78
27	22	49
59	68	127

$\chi^2 = 1.86$; $10\% < p < 20\%$

Cause 221. (cumulative)

First Test

22	82	104
7	49	56
29	131	160

$\chi^2 = 1.30$; $20\% < p < 30\%$

Second Test

22	56	78
7	36	43
29	92	121

$\chi^2 = 1.56$; $20\% < p < 30\%$

Cause 223. (cumulative)

First Test

4	100	104
0	56	56
4	156	160

Fisher; $p = 35\%$

Second Test

Not computed due to non-significant result on first test

Cause 231 (cumulative)

First Test

10	94	104
14	42	56
24	136	160

$\chi^2 = 5.60$; $1\% < p < 2.5\%$

Second Test

10	68	78
14	29	43
24	97	121

$\chi^2 = 5.61$; $1\% < p < 2.5\%$

The results of the above tests indicate some definite differences between the relative frequencies of daytime and nighttime collision causes. Somewhat surprisingly, boat malfunctions, especially steering or control malfunctions, showed as being significantly more of a factor in daytime than nighttime collisions. In our sample, 11% of the collision causes were attributed to boat malfunctions, all of which occurred during daylight hours. In all but one of these instances the boat was underway. While the one instance of the boat not underway is not statistically significant, the ten sample instances of boat malfunction while underway show statistical significance in the comparison of daytime vs. nighttime collisions. The significance level of this cause with respect to all causes is 2.3%, while with respect to causes for boats underway, the level is 1.1%. The comparable significance levels for steering or control malfunctions are somewhat lower, 5.8% and 3.4%, respectively.

Two possible explanations for the difference present themselves. Many malfunctions may be the result of corrosion or improper maintenance, and thus may occur relatively early in boat outings. The theory here is that rusted steering cables, loose control rod ends, and other parts of the mechanical systems that may be loose due to the fact that the operator forgot to tighten them as part of an on shore maintenance function will tend to cause the system to which they are attached to fail rather quickly after startup. As most night outings probably begin during daylight hours, boat malfunctions may tend to occur before dark. Other malfunctions may be the result of pushing a boat beyond the physical limits of its components. Such operation is more likely to occur during the day when the operator may feel it is safer to operate in such a manner.

Another cause showed significant statistical results which might not have been expected. Cause 222, this operator not looking, was coded for 14% of the sample boats in daytime collisions, and for only 2% of the boats which had collisions at night. The significance test levels were

1.4% in comparison with all collision causes and 1.2% in comparison with causes for boats underway. It is clear that boaters are less attentive during daylight. There are probably two major causes for this. Operators probably realize that visibility at night is reduced, causing increased collision risk and so are more attentive. Also, during the day there is more to look at including water skiers, other boats, bikinis, etc.

The remaining causes which showed significant statistical test results in day-night comparisons yield the expected results. The percentage of collision-involved boats underway trying to take an avoidance action is higher in the day than at night. The figures are 36% vs 20% of all causes in our sample, with a better than 2.5% significance level when comparison is made for just boats underway. The corresponding percents of all causes for underway boats not taking avoidance actions are 44% and 68%, with a significance level of better than 5% in comparison with all causes and a level of better than 2.5% in comparison with causes for boats underway.

The day-night difference in the likelihood of an operator attempting to avoid a collision is very likely the result of poorer night visibility and increased operator fatigue at night. These conclusions are supported by the data on more specific causes. When not seen (Cause 211), the boats or objects collided with were more than twice as likely to be unrecognizable at night than during daylight. The primary reason avoidance action wasn't taken when the boat or object was seen was insufficient time (Cause 204). The operator's visibility was so limited or he was so fatigued that when the boat or object was recognized, it was too late to avoid the accident. Also, when avoidance action was taken, the nighttime operator was less likely to see the boat or object in time (Cause 113).

Another means of comparing visibility related causes in day vs night collisions is to examine the relationship of frequencies for causes by classifying them as probably, possibly, or unlikely to be visibility related. Using the same classification as in Figure 16, we obtain the following table, using the same type of analysis as in section 4.2.3.

DAY/NIGHT COLLISIONS BY RELATIONSHIP OF CAUSES TO VISIBILITY

	Two-Boat Collisions[1]			One-Boat Collisions[2]
	Unlikely	Possibly	Probably	
Unlikely	13/2	13/6	3/5	23/5
Possibly	---	7/3	3/6	5/7
Probably	---	---	0/0	1/2

1 In two-boat collisions where one of the causes was coded as unknown, the unknown cause was classified as "unlikely."

2 One grounding with unknown cause not included.

Using the method described in Appendix C, we can classify our sample collisions by the likelihood that a visibility related cause was involved. The results are summarized in the following table.

DAY AND NIGHT COLLISIONS BY RELATIONSHIP OF CAUSES TO VISIBILITY

	Day	Night
Unlikely	36 (53%)	7 (19%)
Possibly	18 (26%)	13 (36%)
Probably	14 (21%)	16 (44%)

47% of daytime collision **causes** are at least possibly visibility related, whereas 80% of nighttime causes are. To see if a significant difference in these percentages exists, we construct a contingency table and compute a χ^2 statistic.

	Not Likely	At Least Possibly	
Day	36	32	68
Night	7	29	36
	43	61	104

We calculate $\chi^2 = 9.55$, for a significance level of better than 0.5%, indicating that indeed, as expected, visibility related causes are more likely in nighttime collisions. Although this result seems obvious, the statistical analyses performed do substantiate our preconceived beliefs and also help validate the cause analysis.

Finally, it should be noted that 3.6% of the collision causes in our sample were classified as improper lighting. This was for both daytime and nighttime collisions. For nighttime collisions the percentage was 11%. Furthermore, while the percentage for all non-fatal collisions was only 1.9%, for fatal collisions, it was 6.7%. Also on 50% of the sample night-operating boats for which a determination could be made, it was found that the lights were not legal. It seems clear that a strictly enforced lighting regulation could significantly reduce collisions and fatalities.

4.2.8 Summary — Visibility Problems

Visibility problems were identified in the Phase I research effort, in all ten of the 1975 in-depth collision investigations, and in half of the causes coded in the data analysis effort. Table 4-1 has been constructed to fit the results together to identify the most common problems.

<u>Problem Areas</u>

The three research efforts have identified several problem areas that if eliminated or controlled could reduce the number of collisions. They are:

1. The boat operator's forward visibility is reduced or obscured by boat structure, people and objects.
2. Sun glare off bright surfaces forward of the boat operator reduces his ability to distinguish objects ahead.
3. Glare from the stern light reduces the ability of the operator to see through the windshield or past the lighted surfaces on the boat.
4. Glare from shore lights reduce the operator's ability to distinguish other boats' running lights.

5. The boat operator isn't looking forward. Instead his attention is on skiers, other people in the boat, etc.

6. The operator doesn't see the object he is about to hit in time to avoid hitting it.

7. At night the boat operator becomes disoriented, makes a gross error in identifying his position and the aids to navigation in his visual field, and runs into seawalls, breakwalls, sand bars and beaches. Stressors might contribute to these problems as well.

TABLE 4-1. VISIBILITY RELATED PROBLEM AREAS

	Phase I Research	1975 In-depth Investigations	Data Analysis	Problems Identified
Forward visibility obscured	Yes. 10% couldn't see forward.	In 19.5% of the cases.	2.4% couldn't see forward.	People, objects, bow obstruct view of water.
Glare problems identified	Yes.	In 20.8% of the cases.	In 86% of known cases or 15% of all cases.	Sun glare - direct, reflected. Glare from stern light. Glare from other sources at night.
Looking away	Yes.	In 12.5% of the cases.	In 45% of known cases or 15% of all cases.	Watching skier; talking with others on boat.
Didn't see other boat/object even though it was visible	Yes.	In 56% of the cases.	In 18.7% of the cases.	Not looking (see above). Objects in way (see above).
Didn't see it in time	Reaction times part of stressor test.	In 16.6% of cases.	In 7.2% of the cases.	Speeding. Stressors (reaction times).
Disorientation and misjudged lights/night	Yes. In 38% of the visibility oriented collisions	In 25% of the cases.	N/A	Night disorientation - navigation aid lighting problems; boat lighting problems, stressors.

95% 145

4.3 Control Forces — Steering Wheel

The VAST experiments measured operator performance decrements as a function of fatigue, alcohol, glare, noise, and shock/vibration, but did not measure effects of steering wheel forces on the operators' performance. Wyle measured the amount of force required to turn the steering wheel on seven boats while they were underway as part of the Phase I research effort. Results were:

1. The probable boat operator population was tentatively defined in Phase I. Maximum sustained steering wheel loads for the weakest members of that population should be somewhere between five and ten pounds measured tangentially on the rim.

2. The results of a steering wheel load measurement study showed that the average sustained force required to turn the steering wheel on a boat is 12 lb (5.44 kg). Since the average was more than the maximum should be, the researchers determined that a problem definitely existed.

3. In addition, maximum intermittant steering wheel loads were measured and were found to be well above 20 lb (9.07 kg) in 29% of the cases. Twenty pounds (9.07 kg) was defined as the upper limit for intermittant steering wheel loads for the weakest segment of the boat operator population.

4. VAST showed that fatigue in general caused a degradation in operator performance. It appears as if steering wheel loads alone are at a high enough level to cause the operator to become physically fatigued.

The measurement or analysis of steering wheel loads was not included in the Phase II collision research effort; therefore, the problem summary must include only the results of Phase I research.

4.3.1 Summary — Steering Wheel Load Problems

The Phase I research effort identified the force required to turn the steering wheel of a boat as a problem area in the safe handling of the boat and in the contribution of that excessive effort required towards the fatiguing of the operator. Specifically:

1. Some intermittant steering wheel loads are so high that some of the population of boat operators do not have the strength to turn the wheel.

2. The average of the range of sustained steering wheel loads is above that which the weakest segment of the boat operator population can be expected to perform without excessive fatigue and is probably (although untested) a contributor to the overall fatigue problem within the total boat operator population.

4.4 Control Forces — Shift And Throttle Levers

Phase I collision research identified problem areas involved with the force required to move shift and throttle controls. No provision was made to continue the research during Phase II. Therefore, the results of the preliminary study performed during Phase I are presented below.

A pilot study was run to determine the force required to move the shift and throttle levers on five boats. The results indicated that a problem may be present. The average breakout force of the levers was almost twice the probable maximum force that can be exerted on the control by the weakest segment of the boat operator population. In addition, the average continuous force was close to the maximum force proposed in the study. Therefore, it appears as if there may be a problem with the force required to move the control levers.

4.5 Noise

During the Phase I research effort, 211 sound level measurements made from the operator's position of boats under power were analyzed. The measurements were taken on boats from 14 ft (4.27 m) to 45 ft (13.72 m) while idling, running at a "normal" cruise speed and at full throttle. Results are presented in Figure 4-7.

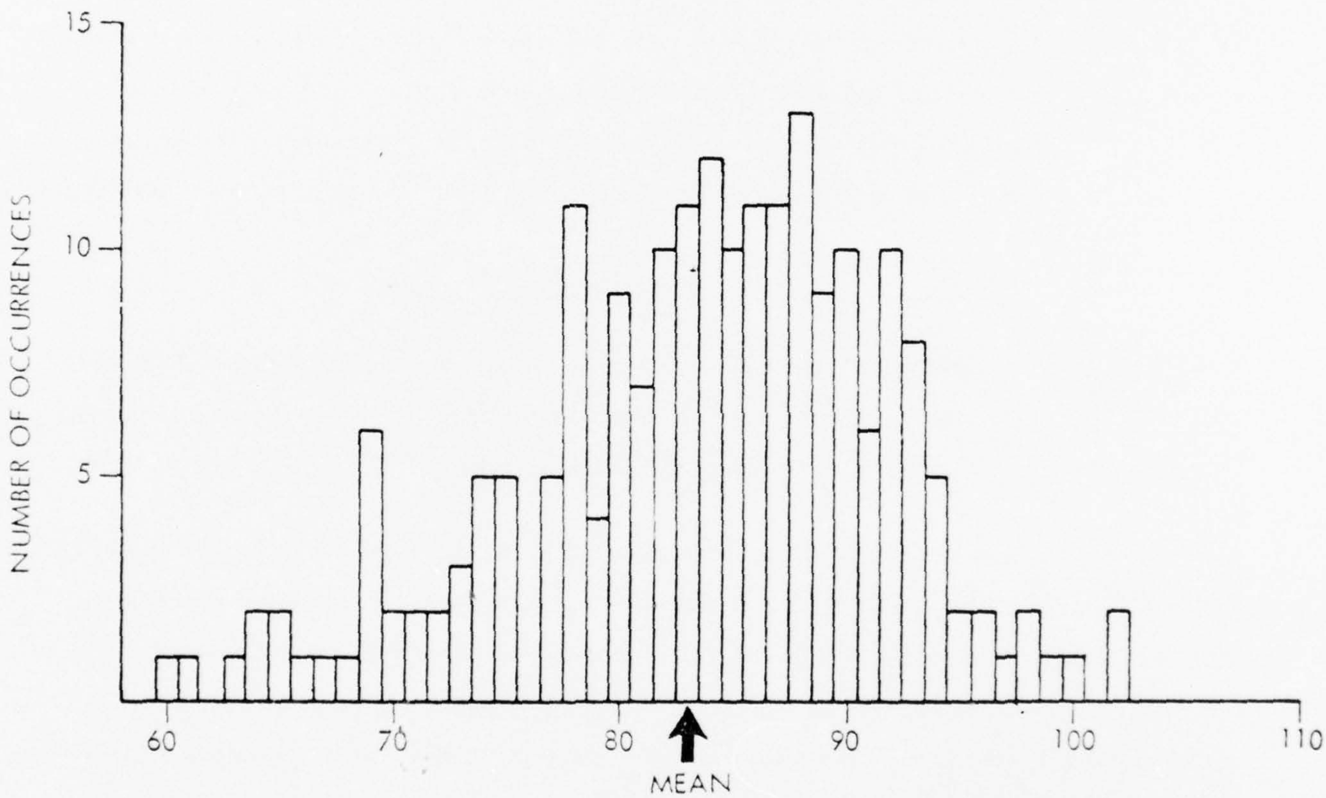


Figure 4-7. Frequency of Occurrences for Sound Levels

As can be seen, sound levels varied from 60 dBA through 102 dBA with a mean of 83 dBA. According to the referenced sources, a significant number of the data points fell with the range of sound levels that:

- mask effective speech communication,
- cause temporary threshold shifts,

- contribute to permanent hearing damage
- may cause other physiological problems which could contribute to the cause of collisions
- may cause operator performance degradations (as shown by VAST)

More startling were the results of Professor A. R. Howell's experiments at the University of Windsor on wind-induced noise levels measured inside the human ear (Reference 24). If one can accept the results of the experiment as being valid, the noise that the operator of an open run-about traveling at 40 mph (64.37 kph) hears from the wind passing his head is approximately 100 dBA. The wind noise alone at speeds over 20 mph (32.19 kph) (≈88 dBA) can cause all of those five problems bulleted above.

The VAST III experiment measured the operator's performance while wearing ear protectors and without ear protectors. Although the attenuation due to wearing the ear protection was not measured, we know that under ideal conditions the ear protectors are designed to attenuate on the average of 20 dB. Being conservative, we can say that the sound levels at the operator's ear during most of the tests were 90 dB without ear protectors and 75 dB with ear protectors. Performance improved when operators wore ear protectors even though they didn't like wearing them. See section 2.0 for details.

As a portion of the data analysis effort, Wyle researchers attempted to determine if they could detect the presence of abnormally high noise levels on the 166 boats involved in the collisions that were being studied. Because most of the information came from BAR's and because the noise problem is not brought out in the BAR's, there were many unknowns. However, of those noise levels that were known, researchers agreed that noise problems existed in 68% of those cases. "Noise problems" were defined as being present when researchers felt that the operator was subjected to abnormally high noise levels for a continuous period of time exceeding one hour.

4.5.1 Summary — Noise

1. Phase I research efforts identified noise as three problem areas: machinery noise, water noise and air noise. The air noise may be the loudest of all.

2. VAST experiments showed that operators performed better when wearing ear protectors.

3. Data analysis effort identified high noise levels on 68% of those boats where the noise levels were known.

4.6 Shock And Vibration

Phase I research identified the vibration characteristics that cause performance decrements and measured vibration levels on boat operators while they were operating in what could be termed as "normal" conditions. Vertical accelerations found in the "normal" boating environment fell within the range of the resonant frequencies of the head, and fell primarily within the acceleration range perceived as "unpleasant" in a highly publicized study. Performance decrements could very well result from vertical accelerations within the measured parameters. See Reference 1 for details.

Performance decrements due to shock and vibration were measured on the VAST III experiment. Although results were only marginally significant, it was found that subjects performed better while sitting on a shock absorbing seat than they did when the shock absorbing feature of the seat was "locked out." This indicates that as the shock and vibration problem becomes better defined, one type of solution might be to improve seat design in boats.

The Phase II data analysis results were quite similar to those of "noise." Researchers agreed that the vibration level was probably uncomfortably high in 65% of the cases where something about the level of vibration was known. (N = 23)

4.6.1 Summary — Shock and Vibration

Phase I research, VAST experiments, and accident data analysis have agreed that shock and vibration on boats operating in "normal" conditions are "uncomfortable" and cause the operator to perform worse in a visual tracking task, and have identified high levels of shock and vibration in boat collisions.

More research is necessary to further define the shock/vibration environment on the operators of boats traveling in "normal" conditions. Shock absorption characteristics of present seating systems must be determined. Finally, after the problems are defined, the contribution of shock and vibration to collisions must be determined.

4.7 Lateral Accelerations

Phase I research identified lateral accelerations as a potential problem area. The amplitude of the lateral accelerations that were measured were well below the point of physical injury.

The frequencies were not measured. Conclusions could not be drawn from the rather incomplete data.

The effects of lateral acceleration was the cause of one collision that was investigated in-depth during 1975 (Collision No. 2, Volume II, this document). The operator standing beside the helm was swept off his feet by the lateral acceleration as he swerved to avoid an oncoming boat. As a result, he lost control of the boat and hit a bridge abutment.

The area needs more research before the problem can be defined. However, because of the lack of accident data due to lateral acceleration problems (we only know of one), the problem should be given a back seat to those that we know are causing many accidents.

4.8 Human Engineering Problems — Control Stations

4.8.1 Introduction

In the Phase I collision research effort, the human engineering considerations within the operators' control station were studied in-depth. Many problem areas were uncovered in runabouts, center console boats, and cruisers (Reference 1, pg 157 through 189). Many of these problems are amplified by the prevalence of certain stressors on these craft. Control station design guidelines for boat builders were recommended as the first step in solving the problems. The Coast Guard has since issued a task assignment to develop such guidelines and, therefore, has effected the solution to the problem. No further discussion is deemed necessary except in terms of the 1975 data analysis effort.

4.8.2 Boat Control Station Problems

Human engineering problems with a control station or controls (Question 8, Figure 3-3, could be identified as being present or absent from relatively few of the accident reports in the data analysis effort. Overall, in 84% of the cases (Table 3-1) no information could be ascertained regarding this possible problem. Most of the information which was obtained came from in-depth investigations. The choice of collision to investigate in-depth was purposely biased towards accidents in which it was thought human engineering problems or operator errors might have been present. One thus must be especially careful in drawing conclusions about human engineering problems from the analyzed data.

For eighteen of the 166 collision-involved boats in the sample, human engineering problems were identified as being present. In two cases they were identified as not being present and in seven cases they were felt to be not applicable.

Because of the small number of cases in which it was determined that human engineering problems were not present, it was decided to base further analysis on only the cases in which these problems were found to be present. Figure 4-8 is a reproduction of Figure 3-4 with human engineering problem data added.

As would be expected, human engineering problems with the control station or controls were found in most cases (three out of four) in which the collision cause was the obstruction of operator vision by something on his boat. A properly designed control station would have eliminated or at least reduced the possibility of such visual obstruction. The other cause which appears to be strongly related to human engineering problems also involves visibility problems. Cause 113 (didn't see other boat/object in time), occurred for twelve of the 166 boats in the sample, and in five of the twelve cases, human engineering problems were identified. To determine how significant the relationship is, we perform chi-square goodness-of-fit test to

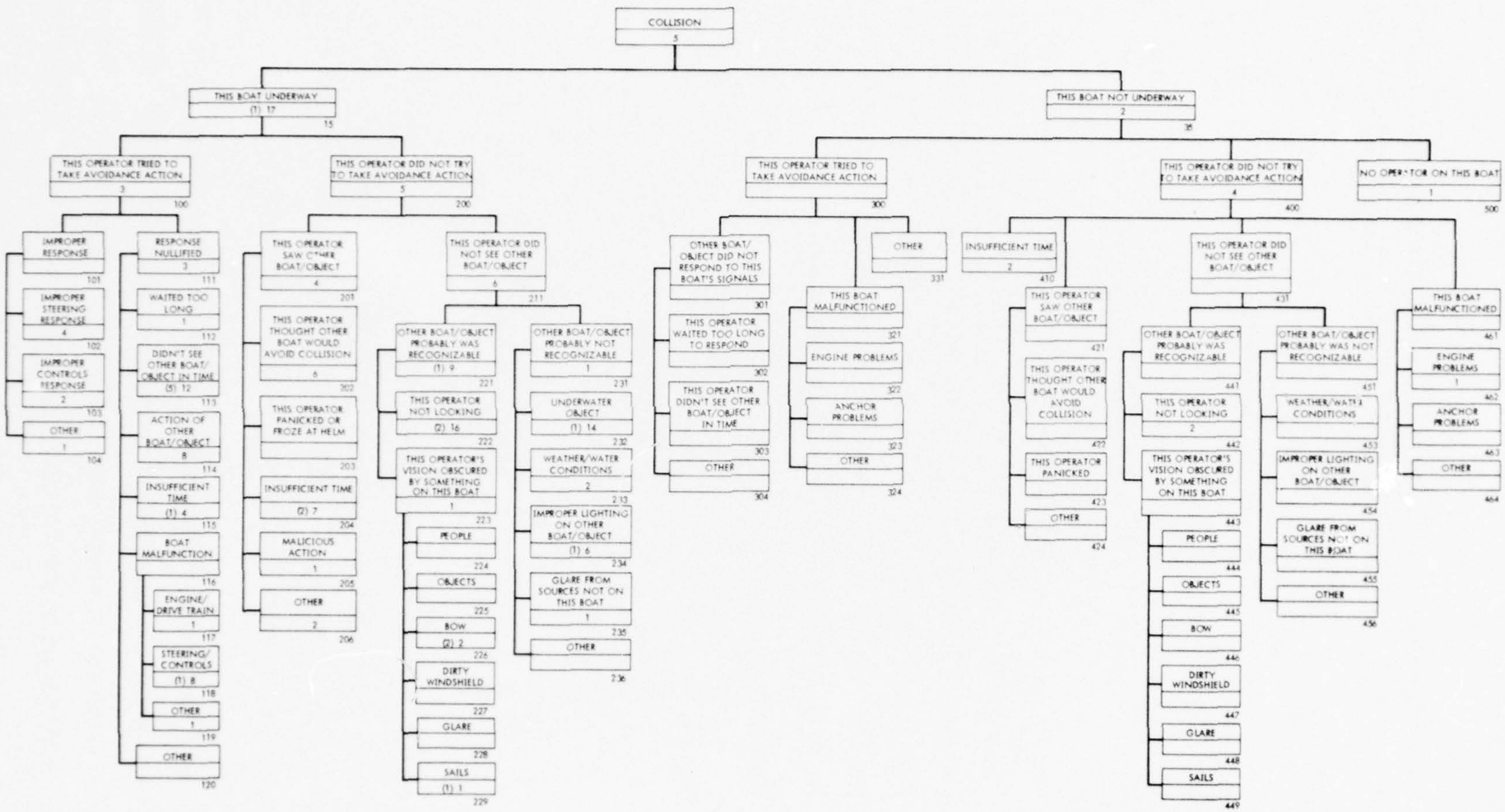


FIGURE 4-8. HUMAN ENGINEERING PROBLEMS ASSOCIATED WITH CAUSES*

* The number of boats on which control station or control human engineering problems were found is given in parentheses, ( ).

determine by how much the distribution of identified human engineering problems varies from the distribution of collision causes with respect to Cause 113. The distribution of collision causes is used to generate the expected frequencies.

	Cause 113	Other Causes
Observed HE Problem Frequency	5	13
Expected Frequency	$\frac{12}{166} \times 18 = 1.3$	$\frac{154}{166} \times 18 = 16.7$

Because one expected frequency (1.3) is less than five, a binomial test will be used instead of the more usual chi-square test. The proportion of human engineering problems one would expect to be associated with Cause 113 is $\frac{12}{166}$. It appears that we have significantly more than that, so we wish to determine the probability of getting a result as or more extreme than the five cases we found associated with Cause 113. That is, the significance level will be the probability of having at least five cases out of eighteen associated with Cause 113 when the expected proportion of cases is $\frac{12}{166}$.

$$\begin{aligned} P\,(X \geq 5) &= 1 - P\,(X \leq 4) \\ &= 1 - \sum_{X=0}^{4} \binom{18}{X} \left(\frac{12}{166}\right)^{X} \left(\frac{154}{166}\right)^{18-X} \\ &= 0.0076 \\ &= 0.76\% \end{aligned}$$

The fact that the human engineering problem data came mainly from non-randomly selected accidents (the in-depth investigations) may be partly responsible for the value of this significance level, but only to a limited extent, as a consideration of visibility problems did not enter into the decisions as to which accidents to investigate in-depth.

This significance level indicates that there is a strong relationship between control station human engineering problems and operators not seeing visible boats or objects that they collide with until it is too late to complete successful avoidance actions. This supports our previous conclusions that cockpit and control design often impair an operator's performance.

5.0 PROBLEM IDENTIFICATION SUMMARY — SAFETY ENHANCEMENT CONCEPTS

5.1 Introduction

Many collision causal problem areas have been identified in the preceeding sections. Some of them have been positively identified and defined. By eliminating or reducing these problem areas, we should be able to reduce the collision rate. The solutions to the problems that were defined, or the "safety enhancement concepts," are listed in this section with suggested standards developments and/or educational programs.

Many of the problems that have been identified require further research efforts in order to define them thoroughly enough to be able to adequately attach solutions or safety enhancement concepts to them. Those problems are listed in Section 6.0 along with a discussion of the unknown areas and the research necessary to adequately define the problem area to the point where solutions may be identified.

5.2 Problem Identification Summary — Safety Enhancement Concepts — Regulation Oriented

1. Problem - Obscured or reduced forward visibility as a result of:

   - poor control station design and/or high trim angles,
   - high cabin or bow,
   - objects forward, or
   - people forward.

   Safety Enhancement Concepts - Regulations

- The problem of poor control station design causing reduced visibility will be partially solved through a task that the Coast Guard is funding in 1976 which will include the development of a voluntary standard for control stations on boats. The concept is that manufacturers would design to a voluntary standard if one existed.

- Minimum visibility standards will become an essential part of the control station design voluntary standard. The control station design process begins with the identification of the spot on the water where the operator must see. A line is projected over the bow of a boat at a predetermined trim angle and a minimum eye point is established. The rest of the control station design evolves from that minimum visibility oriented beginning.

- Care must be taken to present the standard in such a way that small manufacturers without design staffs can assure compliance. For instance, automotive engineers construct visibility envelopes for cars and trucks which define the window areas and associated blind spots in terms of angular projections from the operator's eye. The computerized technique is very successful, but requires trained technicians to do successfully. The boat standard must be simple since such expertise doesn't exist in the industry nor can it be justified in terms of cost. Compliance to the standard will become evident simply by observation and measurements of control stations designed after the standard is published.

Effectiveness of the standard can only be measured by reduction in the rate of collisions attributable to vision oriented causes measured in future data analysis efforts. Obviously, visibility is important to the collision problem. No one (except a few malicious people) will deliberately run into something that is seen and can be avoided; therefore, visibility related problems should be the most frequent problems found. The Phase II data analysis indicates that collision causes related to visibility problems associated with boat design or construction account for about one-fourth of all collision causes. Visibility problems were identified in all of the 1975 in-depth collision investigations.

If we assume that the Phase II data analysis is closer to the real situation and that the in-depth investigations may have been biased because we may have been looking for accidents having visibility problems, then one-fourth of all collisions may have occurred because of a visibility associated problem with the boat.

A calculation of the number of collisions that may be avoided yearly would look like this:

	CG-357-74
Total Collisions	2512
Number of Deaths	157
Injuries *	506
Property Damage *	$ 3,889,000
Visibility Related Collisions (25%)	628
Visibility Related Deaths	40
Visibility Related Injuries	127
Visibility Related Property Damage	$ 972,250

* Reported Figures

If we assume a 20% effectiveness of the voluntary standard, the statistics would look like this:

Number of Collisions Avoided	502
Number of Lives Saved	31
Injuries Avoided	101
Reducation in Property Damage	$ 194,450

The question of how much it would cost to comply with the standard is complex and impossible to answer until the contents of the standard is known. Basically, the standard will dictate cockpit geometry that, when applied in the design stage, will not increase the cost of the boat. However, if the standard dictates seat design changes, control design changes or greater control station space allocations, cost of compliance could become a problem.

The benefits in terms of lives saved at $250,000 per life times thirty-one lives would come to $7,750,000 per year. If we assume that an average of 330,000 outboard boats will be sold each year for the foreseeable future and that 68% of them will have control stations (not operated directly from the engine),

then 224,400 outboard boats built each year should be affected. In addition, 70,000 inboard/outdrive boats and 10,200 inboard boats, or a total of 304,600 boats a year, should comply with the standard. In order to be cost effective, then the cost of compliance would have to be less than $25 per boat.

2. Problem - Sun glare off bright surfaces forward of helmsman including windshield frame, control panel, instruments, chrome accessories, forward deck, chrome or stainless rails and fittings.

Safety Enhancement Concept - Regulations

- Regulate the glare producing or reflective qualities of the material forward of the boat operator.

  The problem is an extention of the visibility problem discussed above and could be partially solved through a voluntary standard that would specify reflective characteristics of all materials forward of the boat operator. Thought may also be given to specifying the amount of specular reflections that can reach the operator eye area. In either case, the cooperation of both hardware manufacturers and boat builders would be necessary. Manufacturers as well as importers of cleats, horns, railings, and windshield frames would have to modify their products to comply with the standard. Boat builders would have to change gel coat colors and possibly experiment with semi-gloss or non-gloss deck surfaces. The method in which the concepts were marketed to the dealers and users would have a lot to do with the success of the project.

  Ford is marketing several automobile models in 1976 with non-gloss hood surfaces; however, these models are in their high performance line and as such are aimed at the young adult market. Historically, the trends that are popular with young adults are modified slightly and become popular with the older generation after a delay of a couple of years. Witness the customizing of cars in the late 50's and early 60's by stripping them of their hood ornaments and

trunk lid openers. Detroit accepted this as a standard. A few years ago, the kids began to raise the rear end of their cars. Now we have the wedge shape which visually does the same thing. The point of this discussion is to demonstrate that marketing dull surfaces on boat bows may not be difficult and a voluntary standard may be effective because the trend has already been initiated by a group with tremendous buying power and, therefore, a great influence on our current marketing system - the young adults.

Determining the number of deaths each year due to glare from on board surfaces is impossible with the data available. We have identified the presence of glare in our data analysis effort, and identified the glare problem as the cause of two of the sixteen in-depth collision investigations (1974, No. 6 and 1975, No. 10). Glare from forward surfaces wasn't measured in the VAST experiments. The operator was surrounded by the light apparatus which was painted flat black to eliminate glare. He couldn't see the bow.

Even though the benefit data doesn't exist, engineering judgment and the fact that the automotive and aircraft industries have identified it as a problem and have regulated it, makes it apparent that regulating the reflective qualities of items forward of the helmsman will reduce glare and hence the collision rate. The voluntary standard concept would probably be the most logical method of handling the problem since it appears as if the benefits cannot be proven. Perhaps, the standard could be part of the control station design standard or it could be developed separately. The development cycle might include:

- establishing criteria,
- developing a standard method of measuring reflections off boat surfaces,
- measuring current products,
- consulting manufacturers to determine the acceptable limits of gloss reduction,

- modifying existing boats and measuring reflections,
- comparing results with criteria and estimated acceptable limits,
- modifying and drafting the standard, and
- establishing compliance measurement and testing procedure.

There is a current trend toward brushed stainless and brushed aluminum surfaces on railing, cleats, etc. One line of cleats and hardware is being marketed in flat black epoxy coated aluminum. Several boat manufacturers currently use flat black anodized aluminum windshield frames on their runabout lines. The cost to comply here is negligable since there is very little difference in cost between the black epoxy finish and clear anodized aluminum.

Gel coat colors vary in their reflectance values from 85% for white to 63% for medium buff to 55% for medium gray. Since the cost difference in gel coat colors when bought in bulk quantities is negligible, the cost of glare reduction from color changes would be negligible. Therefore, the probability is that the cost to comply with a glare reduction standard would be negligible on new boats and quite low on currently produced boats.

Basically, the cost to comply to a glare reduction standard would be the cost of the standard itself. However, it must be tied to an education program designed to inform the boat buyers of the benefits of non-glare surfaces in terms of their safety. The education program must also be directed towards the population that now owns boats and those that will buy used boats or boats built prior to the effective date of the standard. Education concepts, costs and benefits are discussed later.

3. Problem - Glare from stern light reflecting onto cockpit surfaces, windshield, etc., causing reduced night visibility.

Safety Enhancement Concept - Regulations

- Develop new lighting standards that will eliminate the problem. Attach cockpit and instrument lighting standards to the package.

The navigation lights issue has drawn considerable attention recently. It is a difficult one because international and inland regulations often differ concerning proper lighting configurations. The 360° stern light is regarded as a primary glare source by many boaters. Windshield-mounted lights also create considerable glare problems. Fruitful regulatory approaches to navigation light problems appear to be to: 1) develop new or improved lighting configurations to reduce the problems, or 2) adapt current configurations. Since this issue is being hotly debated at present, it is likely that new approaches and ideas will surface.

Cockpit and instrument lighting standards could be developed along the lines of similar standards and recommendations in the aircraft and automotive industries. These standards would involve studies of the uses of various cockpit components and instruments and their positioning. Of course, these standards should reflect the solutions to the overall cockpit design problems. In the automobile industry, for example, there are standards (S.A.E.) governing the positioning of instruments and lighting relative to overhangs, steering wheels, etc., so that instruments are visible and do not result in reflections in the windshield. The cockpit and instrument lighting problem is multifaceted, and complicated by the problems of overall lighting on boats.

Standards that are developed concerning small boat lighting should be performance oriented (as opposed to hardware oriented). Criteria could be written to specify maximum reflectance of on board surfaces - especially in cockpits, visibility requirements for instruments, and lighting levels which must be satisfied in certain areas of the boat. In researching and determining these criteria, the automotive and aircraft research should provide excellent source material. Indeed, some of their results could be applied with only minor modification.

While these standards will necessitate design changes and resulting costs, some of these would have occurred anyway. In addition, once the designers are knowledgeable in the standards, the cost of compliance should be significantly reduced. The effectiveness of the standards could be measured in terms of reduced nighttime collisions and groundings, and, perhaps, reduced discussion of the nighttime glare problem. The standards must not solve the nighttime glare problem at the expense of overall visibility from the boat, or its detectability from another boat.

Education programs could facilitate the impact of these safety measures. Boaters could be instructed to inspect their boats for these problems and solutions could be proposed for them so that they are not forced to turn off their navigation lights in order to be able to see. Education could also be used to inform the prospective boat buyer of some of these problems. See Section 5.3.

BSAC (Boating Safety Advisory Council) has been made aware of the problem through an actual nighttime demonstration of the stern light glare problem and the improvement in visibility that is possible with proposed techniques. Wyle has estimated that at least thirty percent of the collisions happen at night. Problems related to glare from or visibility of the stern light were identified as being responsible for two of the collisions investigated in 1974 and two in 1975 (No. 1 and No. 2). Stern light glare probably contributed to two more 1975 collisions investigated in-depth (No. 3 and No. 6).

A preliminary estimation of the number of collisions that may be avoided would look like this:

	CG-357-74
Total Collisions	2512
Nighttime Collisions (30%)	754
Number of Deaths	157
Number of Deaths - Nighttime (conservative)	47
Injuries	506
Injuries - Nighttime	152
Property Damage	$ 3,889,000
Property Damage - Nighttime	$ 1,166,700

If we assume that 20% of the nighttime collisions could be avoided with a regulation that eliminated glare on small boats due to stern lights, the effect of the regulation would look like this:

Number of Collisions Avoided	151
Lives Saved	9
Injuries Avoided	30
Reduction in Property Damage	$ 233,340

In order to obtain a gross estimate of the feasibility of such a standard in terms of its cost effectiveness, the following calculation was made based on an estimated six dollar increase in the cost of an additional light fixture for all boats less than 26 ft (7.92 m) in length.

BIA recently compiled figures on boats under 26 ft (7.92 m) with inland and international rule lights. Their data shows:

• Total boats under 26 ft (7.92 m)	5,541,937
• Boats under 26 ft (7.92 m) in coastal states	2,791,759
• Boats under 26 ft (7.92 m) in inland states	2,750,178

They assumed:

- Fifty percent of boats (with lights in coastal states conform to inland rules.
- All boats with lights in inland states conform to inland rules.
- Forty percent of all boats under 26 ft (7.92 m) have lights.

Using these figures, we can say that:

• Total boats under 26 ft (7.92 m) with lights	2,216,775
• Boats in coastal states	1,116,703
• Boats in inland states	1,100,071
• Boats under 26 ft (7.92 m) with international lights	558,351
• Boats under 26 ft (7.92 m) with inland lights	1,658,422

Therefore, we can estimate that 30% of all boats under 26 ft (7.92 m) are equipped with inland lights. We'll say that all of the boats in this category will require one additional light fixture. To determine the cost of compliance using these figures, we take 30% of 400,000 (the projected number of outboard and I/O boats built each year) and find that 120,000 boats would have to have an additional light fixture. The total cost for compliance per year at six dollars per boat would be $720,000. When compared to the expected benefit of $2,500,000, we see that the addition of one light fixture would be quite cost effective.

A performance standards development program may proceed as shown below:

- Document present systems.
- Determine minimum visibility standard and measurement techniques.
- Measure glare on a sample of boats with present lights.
- Measure visibility of boats from other boats. Develop minimum standard.
- Develop new systems.
- Measure glare on same boats with new systems.
- Measure visibility of modified boats from other boats.
- Compare and analyze effectiveness vs. cost, etc.
- Consult with manufacturers; determine cost impact.
- Develop performance standards and testing method.

5.3 Problem Identification Summary — Safety Enhancement Concepts — Education Oriented

5.3.1 Introduction

Section 5.2 identified solutions to some of the problems identified as being of a regulatory nature. The purpose of this section is to identify those areas in which educational programs would be helpful and to discuss in general how education should be applied.

The design of educational programs should be preceded by a consideration of the objectives to be met, the approach to be employed, and previous or existing programs. Accordingly, this section proceeds from the general to the specific, including the following components:

- A discussion of the general objectives, orienting attitudes, methods, and media which could (or should) be employed in boating safety education.
- A review and evaluation of some of the existing boating safety education programs.
- Identification and discussion of these collision accident problem areas for which education is the best or only practical solution.

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- For each problem area, a description of the kind of educational program which could be applied.

5.3.2 Educational Objectives And Methods

In promulgating regulations and standards, the Coast Guard has been careful not to unduly restrict or encumber the activities of recreational boaters. Presumably, educational programs should be consistent with Coast Guard policy in this respect. Education should be seen as a source of assistance and advice for the boater rather than as a qualifying hurdle. These considerations suggest that boating safety education should be voluntary and, for example, should not be part of a licensing requirement. Of course, these questions are policy matters which only the Coast Guard can decide.

The design of an effective program should consider at least the following points:

(a) The educational program must motivate the boater to take corrective action.

(b) The program must point out practical and economical actions which the boaters can take to ameliorate the problem.

(c) The educational message must reach the appropriate audience.

An important part of motivating the boater is to clearly identify the problem in a way that relates directly to his activities and experience. In other words, the boater must know where, when, and how the problem can affect <u>him</u>. The boater can also be motivated by relating the risk of a boating accident and its consequences to his world of experience. For example, one might compare the risk of having an automobile collision while driving to his favorite boating location to the risk of a collision in a day of boating. One could also relate the consequences of an accident to the boater's world of experience. For example, suppose that the boater has a collision. What are the chances of a boater losing a member of his family or a friend? What is the expected loss in property damage and inconvenience? How many hours of work would it take him to recover from the monetary loss involved?

In recommending actions which the boater can take, the emphasis should be placed on solutions which are easy to remember and implement. Rhymes or nmenomics can be used to jog the boater's memory. A good example is the rule for determining where one should be with respect to a channel marker buoy - "Red on the right when returning."

The final requirement for an effective educational program is that it must reach the appropriate audience. Current boating safety educational efforts probably fall short on this requirement because they rely too heavily on one medium - courses offered by volunteer or public service organizations. Other possible media include:

- the electronic and other mass communication media,
- specialty magizines and publications,
- public school curricula,
- displays placed in boat dealerships or marinas, and
- publications or instructional programs conducted by boater organizations, such as the Bass Anglers Sportsmen's Society (BASS), sailboat class organizations, sailing or yacht clubs, regional canoe or white-water associations, etc.

The number of boaters reached by boating safety education might also be increased by providing more rewards or incentives for the boaters who complete these courses. Some possibilities include reduced insurance rates and certificates which can be displayed on the boat's windshield.

5.3.3 Review of Existing Boating Safety Education Programs And Materials

Wyle personnel enrolled in boating safety courses offered by the U.S. Coast Guard Auxiliary and the U.S. Power Squadron, and also critiqued the materials and references used in these courses. The purpose of this subsection is to review these courses and evaulate their effectiveness in promoting safe boating practices. It should be noted that these courses were not intended to be exclusively boating safety courses.

The personnel enrolled in the Auxiliary and Power Squadron courses found that they generally failed to address collision accident problems for small boats. With a few exceptions, the

courses neglected accident problems for small craft. The most notable exceptions were a good discussion of fires and explosions in the Auxiliary course and a warning concerning the effect of weather conditions on boats under 16 ft (4.9 meters) in length in the Power Squadron course.

Another important shortcoming in the Auxiliary course was that safety equipment and actions were presented from the standpoint of the need to satisfy the law. There was very little discussion of reasons behind the law; i.e., the consequences of unsafe boating practices.

Finally, the personnel taking the Auxiliary course found the lectures dull and not well planned. Definite improvements are possible by making increased use of audio-visual materials. The course could also be improved by recruiting instructors who have better teaching skills and a greater familiarity with teaching methods.

The following paragraphs present a chapter-by-chapter summary of the materials used in the Coast Guard Auxiliary and Power Squadron courses.

5.3.3.1 U. S. Coast Guard Auxiliary Safeboating Course Book "Boating Skills And Seamanship"

Chapter 1. The Safe Way To Boating Enjoyment

Chapter 1 discusses CG 357 in terms of capsizings, collisions, falls overboard, and fires. PFD's are defined and the various boating activities are discussed in terms of safety. Safe fueling practices are presented as well as practical hints for safe boating.

The chapter contains two paragraphs on the collision problem. The first paragraph says that the failure to maintain an efficient forward lookout is the principal cause of collisions and discusses the water skier problem. The second paragraph discusses problems peculiar to those boats equipped with automatic pilots.

Two statements were made within the chapter that don't appear to be consistent with an attempt to promote boating safety. They are:

1. "Standing up in a small boat is not especially dangerous if it is done carefully in calm water conditions, and if the boat is not too heavily laden." (Page 2)

2. "It is best not to talk about capsizing since this may frighten your crew, but you should have your plans clearly in mind in the unlikely event that this might happen." (Page 15)

Boating accident research has shown that the principle cause of falls overboard is standing up. Falls overboard is the second most prevalent cause of deaths in boating accidents with 22.8% of the total number of deaths in 1974 (Ref. CG-357). Statement number one should be replaced with a section that discusses the standing problem, shows the dynamics of the problem, and tells the reader how to move about safely in a small boat. Small boats should be defined and canoes, johnboats, and other lightweight boats should be discussed separately.

Deaths due to falling overboard are only surpassed by those caused by capsizing. Forty-one percent of the boating related deaths in 1974 were a result of the boat capsizing. The operator/owner of a small boat should indeed discuss the possibility of capsizing with his crew. Statement

number two should be deleted and a section added that discusses the problem with emphasis on the most prevalent causes of capsize and how to avoid it. Again the discussion should center around those boats having the highest probability of capsize, i.e., johnboats, canoes, and other lightweight boats.

Chapter 2. The Sailors Language

This chapter discusses basic terminology in terms of the parts of a boat, the types of boats, and the major construction materials. The text is slanted towards wooden boats and types of boats which are unfamiliar to neophyte boaters such as skiffs, prams, dinghies, and utility outboards. Johnboats, bassboats, and bowriders are never mentioned. The chapter may have value from the informational sense, but it has little to do with boating safety per se.

Chapter 3. Boat Handling

Propeller and rudder theories are discussed in terms of maneuvering the single screw and twin screw boat. One paragraph is devoted to outboard and inboard/outdrive boats. Entering and leaving a dock is discussed in various wind/current conditions. Anchoring is discussed as is heavy weather boat handling. The discussion centers around inboard boats and open ocean handling problems. This chapter should be rewritten with emphasis on small outboard powered boats.

Chapter 4. Legal Requirements

This chapter explains the vessel numbering system, the equipment that each boat must have on board, ventillation systems, and BAR's.

Chapter 5. Rules of the Road

Lighting rules are discussed in detail. The General Prudential Rule is discussed ("the privileged vessel does not, at any time, have the right of way through the hull of another vessel"). Collision avoidance rules are discussed in terms of the international rules of the road, inland rules of the road, Great Lakes rules of the road, and Western Rivers rules of the road. Finally, sailboat right-of-way rules are discussed in detail.

The chapter deals with written rules. Whistle or horn signals in passing situations are stressed. However, horn signals are almost never used by the majority of small boat operators. Real world collision avoidance measures should be stressed. Those problems that we have found that cause collisions plus the safety enhancement concepts should be given a chapter of their own.

Chapter 6. Aids To Navigation

This chapter deals with the system of buoys, lighthouses, etc. The subject seems to be covered quite well.

Chapter 7. Charts And Compass

The use of the compass is discussed as are speed curves, charts, and plotting. The subject is covered quite well; however, more emphasis should be given on the subject of using a chart to find your approximate position on a river or lake without having to rely on compasses, dividers, parallel rules, etc.

Chapter 8. Marine Engines

Internal combustion engine theory is described along with lubrication systems, cooling systems, fuel systems, and trouble shooting. Pre-season and post-season maintenance is discussed with the emphasis on inboard engines. From a safety standpoint, all fuel related components must be maintained — some with steering, etc. This chapter should also include more emphasis on the outboard engine.

Chapter 9. Marlinespike Seamanship

This chapter describes knots and their uses.

Chapter 10. Sailing

The chapter discusses sailing from nomenclature through the basics to heavy weather precautions. It deals with small boats for the most part. A section should be added on the visibility problems associated with sailboats and possible solutions to those problems.

Chapter 11. Weather

Before discussing clouds and air circulations, the authors devote more than a page to an incident in which several people were killed on Lake Michigan due to a storm that had been predicted. Boaters were warned but went out anyhow. The importance of weather conditions on boats less than 16 ft (7.88 m) in length is pounded home. It seems to be a good approach. Consideration should be given to utilizing this technique for collision avoidance education.

Chapter 12. Radiotelephone

The types and usage of the radiotelephone are thoroughly covered.

Chapter 13. Locks And Dams

River boating, dams and the procedures for going through locks are discussed. Safety precautions are pointed out in terms of collision avoidance measures with commercial towboats and their barges.

SUMMARY

The general "feeling" that this writer got throughout the book was that it was directed towards those people who own wooden inboard powered cabin cruisers. The three most popular types of boats that are purchased by the neophyte boater, i.e., johnboats, bassboats, and bowriders, aren't discussed at all. Each of these boats have their peculiar problems in terms of collision avoidance as well as other safety related problems. New boaters should be made aware of these problems as part of this type of course. Therefore, a chapter should be added for each of the three types of boats which would deal with the attributes of each type as well as the problem areas. The kinds of waterbodies and weather for which the boats are suited should be discussed as should safety gear and rescue procedures for each. Common causes of collisions (as well as other types of accidents) should be discussed for each type of boat.

5.3.3.2 United States Power Squadron Basic Boating Course

STUDENT'S FOLDER

Section 1. Handling Under Normal Conditions

The first chapter deals with the skipper's responsibilities, fire prevention, capacity labels, trimming the boat, turning and stopping, reckless operation, boat flotation, PFDs, small craft advisories, and water skiing safety fundamentals. The material is aimed at the outboard runabout owner. No mention is made of johnboats, bassboats, or bowriders. Overloading, swamping, and fires are mentioned, but collisions or collision avoidance aren't mentioned.

Section 2. Handling Under Adverse Conditions

Broaching, pitch-poling, poor visibility, swamping, capsizing, man overboard, and fire are discussed in terms of the small boat. Collisions are never mentioned, even in the visibility section, although stopping in half the visibility distance and keeping a sharp lookout are mentioned.

Section 3. Seamanship And Common Emergencies

Fueling practices are discussed as are towing procedures, carbon monoxide, lightning, distress signals, and useful knots. Collisions aren't mentioned.

Section 4. Rules Of The Road

The introduction states that the sole purpose of the rules of the road are to prevent collisions. Sound signals are discussed, as are special rules between sailboats.

Section 5. Compass And Chart Familiarizing

Compass basics and chart basics are discussed.

Section 6. Aids To Navigation

Chart symbols are described.

Section 7. Running Lights And Equipment

Legal lighting is described.

Section 8. Inland Boating

Grounding and collisions with bridges, buoys, and piers due to current are discussed. Collision precautionary measures are described concerning dams, spillways, shoals, and river maintenance obstructions.

Section 9. The Mariners Compass And Piloting

Variation and deviation are explained. Sample problems are given.

Section 10. Boat Trailering

Self explanatory.

SUMMARY

The text was aimed at small boat owners; however, specific problems of johnboat, bassboat, and bowrider operators aren't mentioned. The same comments apply here as were discussed in the C. G. Auxiliary course summary.

5.3.4 Educational Recommendations For Collision Accident Problem Areas

The previous sections have identified collision accident problem areas and outlined some general considerations for educational objectives and methods. The purpose of the present section is to identify those problem areas which are most amenable to educational solutions and to outline the kind of educational programs which would be helpful in each area.

Before discussing specific problem areas, it is worth considering the role which education can play in relation to regulation. First of all, Coast Guard policy makers need not be forced with an either/or situation; i.e., either regulation or education. The two approaches can complement one another. In fact, the best approach to a problem area will almost always involve a combination of regulatory and educational programs. Two examples come to mind. When a new standard is promulgated, it typically applies only to newly manufactured boats. Obviously, this does nothing for users of older boats. However, there are generally actions which the users of older boats can take to reduce their exposure to risk associated with a particular problem area. Educational programs can be designed to alert users of older boats to these problem areas and suggest corrective actions.

The second case occurs when new standards are introduced which, in order to be fully effective, must be complemented with appropriate behavior on the part of the boater. An example is level flotation. If boaters typically abandon a swamped craft, level flotation cannot be fully effective.

Reviewing the problem areas identified in earlier sections, it is apparent that education is applicable in at least a limited way in all cases. This is true even for those problem areas which will be identified as requiring further research before effective regulations can be formulated. These areas include:

1. nighttime collisions due to misidentification of lighted aids to navigation,
2. confusion between shore lights and navigational lights on other boats in nighttime collisions,
3. high noise levels aboard boats,

4. shock and vibration,
5. lateral accelerations, and
6. excessive force levels required on some control levers.

Consider, for example, the way in which education could be applied to the problems of misidentification of lighted aids to navigation and confusion of shore lights with navigational lights on other craft. An educational approach to this problem would cover the following points:

1. Describe the problem, including accident scenarios tailored to the type of craft and environment in which the audience operates. Possibly simulate appearance of shore lights or boat lights with a light board model.
2. Discuss the risks involved, including loss of life and property damage.
3. Describe navigational lighting practices in the principal boating area for the audience. Stress the importance of correct lighting on the participant's boats.
4. Discuss precautionary measures including:

    (a) navigational and piloting practices for the areas of concern, and
    (b) methods of detecting other boats and hazards.

The discussion of methods of detecting other boats and hazards should include the testimony of experienced boaters in the area. This information could be used in conjunction with experience on the water, movies, or still photos of the areas of concern under a variety of lighting and weather conditions.

Obviously, the entire program outlined above could not be covered in a single presentation in certain media. A single television or radio spot could cover only a small portion of the above material. A television spot might include an accident scenario to illustrate one type of problem and an appropriate piloting or detection method which would have prevented the accident.

Another group of problem areas related to boat equipment can be approached in part by education and in part by regulation. These problem areas include:

1. high noise levels,
2. shock and vibration,
3. lateral accelerations,
4. excessive force levels required on some control levers,
5. reduced forward visibility,
6. sun glare from bright surfaces on the boat,
7. glare from the stern light reflecting on forward surfaces, and
8. momentary and sustained excessive force requirements on steering wheels.

An educational program for these problem areas could include the following topics:

1. Discussion of the problems in the form of a scenario tailored to the audience craft and operating environment.
2. Discussion of the consequences of the problem - loss of life, property damag temporary hearing loss from noise, etc.
3. Preventative or corrective measures, including:

   (a) information which will help the boat buyer select a boat whose design minimizes the problem, and
   (b) operational practices which minimize the problem.

Simply making boaters aware of some of the above problem areas should help them avoid collision accidents. The presentation of these problem areas in the mass communication me may also have other benefits, including:

1. increased sensitivity to the problems and possible voluntary corrective actio on the part of boat manufacturers, and
2. increased public awareness of the Coast Guard's boating safety program.

A final group of problem areas is probably amenable to solution only through education. These include:

1. operator inattention; e.g., not looking forward, but instead, talking with passengers or attending to some other task,

2. excessive speed for visibility conditions, especially at night,
3. effects of stressors such as alcohol and fatigue on the operator's performance, and
4. reduced visibility due to people forward of the operator.

These problem areas are especially difficult to deal with since they are essentially behavioral rather than equipment or environment oriented. In operator inattention, for example, the basic problem is not inadequate equipment or a hazardous environment, but the operator's behavior which is incompatible with attending to the piloting task. These behaviors may include talking with other passengers, watching a water skier, getting a soft drink or beer out of a cooler, or watching objects not in the path of the boat, to mention only a few. These behaviors occur because they are more rewarding than the piloting task. In order to change the operator's behavior an educational program must associate attention to the piloting task with positive or pleasant consequences and inattentive behavior with negative or unpleasant consequences. This type of program is probably best accomplished through the mass media such as television and radio. Two possible themes for television spots are:

1. Present an attentive boater as a personally competent person (e.g., he knows how to handle a boat, how to deal with people, is highly attractive, etc.). Also, expose the same audience to an inattentive boater portrayed as personally incompetent (e.g., stumbles around dock or into the boat, mis-handles people, over-reacts, is unpopular, etc.).
2. Present a condensed accident scenario in which inattentiveness leads to a sudden and dramatic accident.

Similar programs could be designed for the other problem areas mentioned above, including excessive speed at night, use of alcohol or allowing oneself to become excessively fatigued, and allowing passengers to obstruct one's view when operating a boat.

5.3.5 Summary

From the foregoing discussion, it is clear that: (a) educational programs are applicable, as at least a partial solution, in all the collision accident problem areas, and (b) that the application of education to these problem areas is relatively straightforward. Table 5-1 summarizes the way in which education can interface with regulation and further research in each problem area.

It seems clear that flexible and innovative applications of educational technology could have an appreciable impact on the collision accident rate in recreational boating. In order to accomplish this objective, the content and methods employed in current boating safety programs will have to be extensively modified and augmented. Boating safety courses should be revised to include at least the following three elements:

1. a presentation and discussion of collision accident problem areas,
2. the consequences to the boater of various types of collision accidents, and
3. practical and economical means which the boater can use to avoid or minimize each problem.

A better effort should be made to relate the material in boating safety courses to the student's circumstances, experience, and capabilities. There should be increased use of audio-visual aids and better training or screening of potential instructors. Classroom content should be complemented by practical on-the-water experience wherever possible. Last, but very important, additional media should be employed on a wider scale to reach a larger proportion of the boating public and to facilitate the presentation of certain special kinds of safe boating information.

Proposals for the development of educational programs are presented in the Advanced Development section of this report.

TABLE 5-1. SUMMARY OF SUGGESTED APPROACHES TO COLLISION ACCIDENT PROBLEM AREAS

	Problem Area	Suggested Approach
1.	Nighttime collisions due to misidentification of lighted aids to navigation.	Education to make boaters aware of the problem area and suggest compensatory actions where possible, plus further research and eventual modifications in navigational lighting conventions.
2.	Confusion between shore lights and navigational lights on other boats in nighttime collisions.	(Same as above.)
3.	High noise levels.	Education (as above) plus further research leading to new standards.
4.	Shock and vibration.	(Same as above.)
5.	Lateral accelerations.	(Same as above.)
6.	Excessive force levels required on some control levers.	(Same as above.)
7.	Reduced forward visibility due to equipment forward of the operator.	Education (as above) plus standards development.
8.	Sun glare from bright surfaces on the boat.	(Same as above.)
9.	Glare from the stern light reflecting on forward surfaces.	(Same as above.)
10.	Momentary and sustained excessive force requirements on steering wheels.	(Same as above.)
11.	Operator inattention; e.g., not looking forward, but instead talking with passengers or attending to some other task.	Education emphasizing use of the mass media to reach a larger proportion of the boating public.
12.	Excessive speed for visibility conditions, especially at night.	(Same as above.)
13.	Effects of stressors such as alcohol and fatigue on the operator's performance.	(Same as above.)
14.	Reduced visibility due to people forward of the operator.	(Same as above.)

6.0 PROBLEMS REQUIRING FURTHER RESEARCH

6.1 Boat Design Parameters

In Section 5.0 collision causal problems were identified and their associated solutions were defined in terms of regulations or education programs. Many problems that were identified require further research efforts in order to define them thoroughly enough to be able to attach Safety Enhancement Concepts to them. In this section, the problems will be identified and possible approaches to finding solutions to those problems will be explored.

1. Problem - nighttime visibility

   Visibility problems associated with nighttime collisions were identified. An estimated forty-seven deaths resulted from nighttime collisions in 1974. Our data shows that 80% of the nighttime collisions were visibility oriented. Therefore, an estimated thirty-eight lives were lost in 1974 due to nighttime visibility problems. Typically, the operator became disoriented and/or mistakenly identified his position through information received from lighted aids to navigation. Before solutions can be identified, more must be known about:

   - nighttime stressors and their effects,
   - collision area lighting details including navigational aids and background clutter in areas with a high nighttime collision rate,
   - similarities within the accidents in terms of the visual picture that the operator sees, and
   - his approach to plotting his position including an analysis of his use of the information available to him.

   For some reason, many boaters are making mistakes in approaching inlets and harbors. They run into or over the breakwalls. The typical mistake seems to be an error in position and track identification using available information sources. It seems to be a two part problem with both parts needing further research. First, we must find out what information the operator uses to determine his position and track and how he uses that information. For instance, the Power Squadron teaches position plotting techniques using aids to navigation, the compass, and government published charts, along with

pencils, straight edges, triangles and lots of time. But, runabout operators aren't fortunate enough to be able to lay a chart out flat and plot their approach to a harbor in the classical way. At best they have a folded chart positioned somewhere nearby where it won't get wet or blow away. Do they go through the same processes to determine their position with the main difference being that they do it mentally? Can one compute, store, and process that amount of information mentally while driving a boat? Given that it is possible, how accurate is the mental positioning technique? What role do nighttime stressors play in one's ability to determine his position? What are the nighttime stressors anyhow, and how can they be measured?

In order to answer some of the questions presented above, the approaches to harbor entrances having a history of nighttime breakwall collisions should be studied at night from a boat. The approach to each harbor should be made from various angles. A task analysis of position and track identification methodology should be constructed. Problems dealing with locating and interpreting the aids to navigation should surface. Local Coast Guard units should be asked to contribute their expertise in all cases. An example of the contribution that local Coast Guard units may make is one that occurred last year during the investigation of a nighttime collision. The unit chief explained a situation that occurs when one is approaching the harbor entrance from a particular angle. The red flashing light that marks the channel entrance becomes aligned with a radio tower on land which also has a red flashing light. The radio tower appears to have two flashing red lights; one above the other. The aid to navigation visually disappears. The unit has documented several accidents plus numerous complaints caused by the unfortunate situation. Concurrently, the victims of nighttime harbor entrance collisions should be interviewed to determine the process by which they determined their position and precisely what they did or did not do that led them to misjudge their position and, therefore, crash.

Results from the task analysis, the analysis of local knowledge of problem areas, and the analysis of collision victims' testimony should yield:

- the method with which one determines his position and track,
- the usage of the navigational aids,

- the adequacy of those aids,
- the problems, including common problems, and
- possible solutions.

Nighttime stressors can contribute to the problems outlined above. These stressors might include: dark adaptation, lack of color vision, cold, nighttime glare, shore lights, and other environmental problems in addition to the carry-over stressors from daylight hours (cumulative glare, noise, shock, vibration, alcohol, etc.). Laboratory or field studies of some of these stressors could be undertaken using techniques similar to those of the VAST program. The VAST boat could be rigged with alternative navigation light configurations. With the VAST display altered slightly (made dimmer), VAST could be used as one means of measuring the relative merits of different navigation light configurations and some stressor effects. As data above are gathered, knowledge concerning nighttime stressors can also be pursued, particularly those stressors that are relevant to the position and tracking tasks upon entering a harbor.

2. Problem - glare, nighttime

Glare from shore lights has been identified as a problem in that it tends to mask the navigation lights on other boats. This problem is closely related to No. 1 above and should be studied in a similar if not identical manner. As with No. 1, more must be known about:

- nighttime stressors and their effects,
- the background clutter in areas with a high nighttime collision rate,
- similarities within accidents, and
- operators' approach to visual detection of other boat traffic.

The problem of background lighting clutter hiding or masking the navigation lights of other boats is a complex one which not only involves the shore lights but also involves the impairment of the visibility of the boater due to stressors, and visibility on his own boat like glare from his own stern light or instrument lights, dirty windshields, etc. Glare from one's own stern light is being handled in Safety Enhancement Concept, Problem No. 3; however, it will also be considered in certain phases of this research effort in terms of its detrimental effects.

The nighttime collision survey and the in-depth investigations showed that a masking problem due to shore lights exists. Before we can determine what to do to reduce or eliminate the problem, we must learn more about how one currently distinguishes the lights of a boat against the background clutter. To accomplish this, Wyle recommends a three step program. First, nighttime collision victims should be interviewed to determine the details of background clutter, the other boat's lights, how far away the other boat was when the lights were seen, what lights were seen, what color were the background lights, etc. This would be similar to the Nighttime Collision Survey (Reference 3), but would home in on the specific problem area. The survey could be done at the same time as the one suggested in No. 1 above.

The second part of the program would include identifying areas where many accidents of this type have happened. These areas may be the same ones as identified in No. 1. If so, the research can be accomplished concurrently. Wyle researchers along with local Coast Guard representatives and possibly collision accident victims will go out on the water at night and re-enact some of the collision situations to determine how the lights were masked by background clutter. Details will be recorded and analyzed.

The third step will be to devise and test lighting concepts that will tend to stand out against the background clutter. These may be lights that could be added to a boat in addition to the required navigation lights (mast head strobes), or perhaps they could be changes to current lights (make them flash, or brighter, or different colors), or perhaps they could be a new lighting system to replace the current one (headlights, the boat glows, who knows what?). The tests would include evaluation in terms of reducing stressors such as glare, night blindness, etc. Recommendations will be made concerning changeover processes, costs, and the benefits that could be expected.

3. Problem - noise

Noise levels on "normal" boats travelling at "normal" speeds has been measured at levels which can cause temporary and permanent hearing problems. The perceived noise is a combination of machinery noise, water noise, and air noise. Regulations can affect the reduction of machinery noise, but more research is needed in the areas of water noise and air noise. The reduction of noise levels in VAST lead to marginally significant improvements in performance. We need to learn more about:

- how much noise reduction is enough to improve performance, one we know where and how we can reduce noise.
- noise that a hull makes as it passes through water,
- water noise levels as a function of hull size, material, shape, and the effect of superstructure configuration on masking the water noise,
- air noise, and the effect of wind shields.

We know that boats make so much noise that effective speach communication is not possible at most operator locations, and hearing damage both temporary and permanent is quite possible on most power boats. The problem is that water noise as it impacts the hull and air noise as it passes the operator's ears may be so high that lowering the noise level of the machinery may have little or no effect on the overall noise level. Before effective exhaust noise regulations can be recommended we must accurately define the levels of water and air noise.

Most of the background work has already been done. We know the current noise levels on a large sample of boats. However, noise levels measured on board were a combination of the water and machinery noise. Further research is necessary to separate the two. In addition, research is necessary to measure the effects of air noise. Wyle proposes the following program.

Record the noise levels of approximately ten types of planning powerboat hulls at the control station while being towed at 10, 20, 30, and 40 mph (16.09, 32.19, 48.28, and 64.37 kph) (if possible). Record the noise levels at the helm station of the same boats while they are underway on their own power. Analyze the difference. Determine if a reduction in machinery noise could have lowered the overall noise level. At the same time, contact Professor A.R. Howell at the University of Windsor. Attempt to gain access to the special microphone devices that were planted in the subjects' ears during their [illegible] noise research program. Perhaps a detailed system description would be adequate. Wyle could duplicate it.

Measure the noise levels within the operators' ears on the same ten test boats. Compare and analyze. Construct wind screens forward of the operator. Measure, compare, and analyze.

The results of these tests will allow us to determine at what level machinery noise reduction regulations will be effective. For instance, mufflers on drag boats may lower overall noise levels, but further quieting of many outboards may not.

What good is it to regulate machinery noise at 86 dBA when the operator may be hearing 110 dBA in water and air noise at 40 mph (64.37 kph)? Perhaps a curve can be drawn for each boat type (or perhaps one general curve) for water and air noise as a function of speed. Machinery noise regulations may be proposed that would not raise that curve at any speed. The maximum machinery noise, then, would have to maintain a level of 10 dBA under the air and water noise. Of course, there would be a minimum speed where the curve would begin. This would allow machinery noise to increase as speed increased, and is probably much more realistic than a single maximum noise level for machinery (or for the system).

Results may also indicate the need for wind screens on fast boats, optimum control station placement from the noise standpoint, and the noise producing qualities of various hull shapes and types.

4. Problem - shock and vibration

Shock and vibration have been identified as problem areas; however, much more research is necessary before the solutions and the problems can be identified. VAST has indicated that the use of shock/vibration dampening seats can improve performance in some circumstances. We need to know more about:

- the ranges of frequencies and amplitudes of shock and vibration on boats and on boat operators,
- vibration damping characteristics of present boat seats,
- effects of improved seating on operator shock and vibration levels, and
- effects of improved seating on operator performance.

First, the shock and vibration envelope must be defined on a representative sample of boats. It may be most cost effective to use the same ten boats as were used in the proposed noise research in No. 3 above. All will be under 20 ft (6.10 m) and will cover as broad a range as possible of hull shapes, propulsion types, and hull materials.

The shock and vibration portion of the research effort may be as follows: Laboratory tests can be designed to reporduce the vibration and shock environments found in the field. The damping characteristics of presently used seats can be determined. Performance measurements can be made using the VAST apparatus on vibration tables in the laboratory. Shock and vibration absorbing seats can be installed, their damping characteristics accurately measured and operator performance measurements can be made again. The differences in performance, if any, can then be attributable to the damping qualities of the seats.

5. Problem - control level forces

The inability of the weaker segment of the boat operator population to be able to move the control levers in some instances may contribute to the collision problem, but will most probably contribute most to the overall fatigue problem. More research is needed to:

- define the size of the problem, and
- study breakout forces and minimum forces.

There are really two problems here. Both can be researched concurrently. In one case, some control handle loads may be so high that a portion of the population will not be able to move the control. In the second case, the abnormally high forces required may cause problems in accurately controlling the boat speed.

We know from the results of a small pilot study that the force required to move some levers is more than some members of the boating population can apply to the lever. We don't know how many times this phenomenon occurs. We don't know the differences in ranges of force required to move the levers as a function of boat size, control type, or propulsion type. Perhaps the problem only exists on twin station cabin cruisers, or one brand of stern drive. Or perhaps the problem occurs because of a dealer set-up problem, or component mismatches.

We obviously need to take more measurements on more types of boats to adequately define the problem. Therefore, the next research phase should consist of developing a universal measurement and recording device and measuring the control lever forces on a large sample of boats - say fifty. Control manufacturers should be contacted when problems are noted. Attempts will be made to determine the practical aspects of reducing forces required in terms of development costs and equipment cost increases.

6(a). Problem - steering wheel loads - intermittant

Steering wheel loads on some boats under some conditions are so high that a portion of the boat operator population are unable to turn the steering wheel.

6(b). Problem - steering wheel loads - sustained

Normal steering wheel loads measured on some boats are considerably higher than the amount of force that the weakest segment of the boat operator population can apply to the wheel over a prolonged period of time.

More research is needed to:

- further define the problem (measure the steering forces on the wheels of a larger sample of boats),
- define load limits based on the boat operator population, and
- use modified VAST apparatus to measure performance decrement due to fatigue caused by steering wheel load.

As outlined above, the problem needs further definition. More steering wheel force measurements must be made on a large sample of sizes and types of boats at various speeds and under various load conditions. At the same time, maximum permissible intermittant loads and sustained loads should be determined.

The effects of excessive steering wheel loads on operator performance should be measured using the VAST apparatus. In this case, the apparatus could be used in the laboratory, or in a modified VAST field experiment (see No. 7 below). A visual tracking task can be set up in lieu of the compass course following task that

is used in the field. The steering system can be modified to give three or four levels of friction. Reaction times and error rates involving the VAST apparatus and the error rate in the tracking task can all be used as measurements of performance decrement due to wheel loading.

Maximum loads can be defined based on operator performance. Steering hardware manufacturers can be contacted to determine the impact of load standards on the industry.

7. Problem - Daytime Glare

In preceeding sections, the problem of daytime glare was dichotonized into two problem areas: 1) on boat glare, and 2) cumulative glare. The former has been discussed as primarily a temporary glare problem relating to reflective surfaces in cockpits and on decks. The latter problem was discussed to some extent in the VAST experiments. It was found that exposure to glare throughout a boating outing could lead to performance degradations on visual/response tasks. A regulatory solution for on boat glare is proposed within this report. Further study of this problem may lead to a better definition of its magnitude and scope. Cumulative glare has not been studied outside of a few VAST runs, and those indicated that it was a problem.

Further analyses of these problems can be accomplished jointly with the control forces research using VAST. With the design of a tracking task to replace the compass task on VAST, there would be no need to subject the VAST computer to running on the water. Subjects could be fatigued by driving other boats on the water with various glare/cockpit/control force characteristics and then asked to perform VAST tests while sitting still, using either the light display or the tracking task as the primary task and the other as secondary, depending upon the application. Control data could be gathered by testing subjects prior to fatigue and having some subjects unexposed to glare sources (sunglasses, caps, etc.). The tracking task on VAST could be rigged with various control forces to allow measurement of degradations due to the problems outlined in Nos. 5 and 6 above. This study would involve a low risk of computer failure since the VAST boat would never be underway. The experiment could gain data concerning: on boat glare, cumulative glare, cockpit arrangements, steering and control forces, and fatigue.

6.2 Educational Programs

This section reviews some major problem areas anticipated in the development of effective educational programs for reducing recreational boating collisions. Alternative solutions are offered for each problem area. Of course, it should be recognized that other unanticipated problems and solutions may emerge as educational programs are pursued.

Four major problem areas have been identified in the development and implementation of new educational programs:

a. modifying programs offered by local volunteer organizations without destroying local incentive or engendering unnecessary resistance,

b. overcoming monetary problems encountered by local volunteer organizations in paying for revised boating safety course materials and other media (e.g., TV and radio spots),

c. exposing the greatest possible proportion of the boating population to the educational message(s), and

d. minimizing attrition and maximizing the effectiveness of boating safety courses.

Problems in modifying existing boating safety courses can be minimized by encouraging the participation of local volunteer groups, such as the Coast Guard Auxilliary, the U.S. Power Squadron, the Red Cross, and the National Boating Safety Council. This should be done at two stages. Ideas can be solicited from local organizations in the early phases of development, and some groups could be consulted later to review and comment on prototype programs.

Monetary problems in the adoption of new programs can be minimized by Coast Guard financial assistance to local groups. This assistance might take the form of materials provided free or at low cost and funds to help local groups purchase television and radio time for boating safety spots. Local boating safety groups should be identified in such spots in order to increase participation in their programs and provide additional incentive for the group to adopt the revised educational program.

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Exposing the boating public to the educational message is probably the most important and difficult problem area. According to the Nationwide Boating Survey (Reference 25). Twenty-five and seven-tenths percent of the primary operators of recreational craft report that they have taken a boating safety course. This exposure rate could probably be increased substantially if a concerted effort were made to disseminate information and provide incentives for taking boating safety courses. Some possible measures include:

a. Ask boat dealers to distribute a pamphlet to all purchasers of boats (or require that such a pamphlet be included on new boats). The pamphlet would briefly emphasize the need for boating safety instruction and provide information about the source and schedule for courses. The pamphlet should also point out incentives (such as reduced insurance rates).

b. The use of television, radio, magazines, and newspapers to announce boating safety courses and motivate boaters to participate.

c. The use of various incentives for taking a boating safety course, including:

- reduced insurance rates,
- recognition of graduates by publishing their names in a local newspaper or other media,
- a safe boater certificate which the graduate can attach to his boat or car, and
- development of on-the-water test courses which award certificates of "seamanship" to graduates of boating safety courses.

The on-the-water test courses would be open only to graduates of boating safety courses in order to provide incentive to take such courses. Such courses could be operated either by the Coast Guard or local boating organizations. They would be empowered to award ratings of seamanship skill based on the operator's performance. Two possible types of test courses are: a) nighttime navigation, and b) maneuvering, including water-skier towing, pick up for a man overboard situation, collision avoidance, etc. In addition to providing incentive to take a boating safety course, such a test program would improve participants' skills, provide useful data on operator performance, and help to publicize the Coast Guard boating safety program.

The last major problem area mentioned above is minimizing attrition from boating safety courses and maximizing their effectiveness. Several measures suggest themselves:

a. better training and/or screening of instructors,

b. using shorter and fewer class sessions,

c. increased use of audio-visual aids, and

d. encouraging more active participation by the students.

Of course the program of incentives suggested above should also help to reduce attrition. Further discussion of objectives and methods for boating safety education are discussed in the portion of this report entitled "Application of Education to Collision Accident Problem Areas."

Based on the present discussion of problems and solutions and the foregoing discussions of educational methods (see Section 5.3 of this report), it is possible to outline a possible program for the development of boati. g safety educational programs. The plan outlined below would encompass all the major types boating accidents. It seems clear that a single comprehensive revision of boating safety education programs would be more economical, more effective, and would engender less resistance than piecemeal alterations for each accident type.

The program would consist of four components:

(1) Assessment of potential benefits of improved boating safety education programs - This assessment would consider all the major accident types and the widest possible range of educational methods.

(2) Develop guidelines for the revision of boating safety courses and their materials based on results of the benefit assessment, the review of educational methods, and inputs from boating safety organizations. Develop a revised boating safety education course and materials and conduct a preliminary test of their effectiveness.

(3) Develop prototype boating safety programs for the mass media (television, radio, newspapers, etc.) based on results of the benefit assessment and the review of educational methods. Conduct preliminary tests of the effectiveness of these programs.

(4) Develop an incentive program to encourage participation in boating safety courses and to reduce attrition from such courses. Test prototypes of the incentive programs on a segment of the boating population. Also, conduct further tests of the revised boating safety courses and prototype mas media programs. Evaluate the effectiveness of the overall program and suggest revisions. Project future educational needs based on the success of the revised educational programs, trends in accident statistics, and trends in boat and boater exposure.

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APPENDIX A

DEFINITIONS - COLLISION CODING TREE

15	This boat underway	- The boat has to be moving in relationship to the bottom.
100	This operator tried to take avoidance action	- You know that the operator saw the other boat/object and that he probably made some effort to maneuver his boat to avoid the collision. Code this block if you don't know what that action was.
101	Improper response	- The operator made an improper response; however, we aren't sure what it was. This box will seldom be used since we should, normally, know what the response is if we are sure that the response was improper.
102	Improper steering response	- The operator didn't turn enough, turned too sharp, turned the wrong way, etc.
103	Improper controls response	- The operator moved the wrong lever, pushed it the wrong way, etc.
104	Other	- Any improper response that isn't covered above. Code "other" when you know what the response was and know it was the wrong response. Code "improper response" when you don't know exactly what the wrong response was.
111	Response nullified	- The operator attempted to avoid the collision, but something happened after his avoidance attempt to cause the collision to occur anyhow. Code this block when you are sure of the above statement, but aren't certain what that action was.
112	Waited too long	- The operator saw the other boat/object for some length of time before the accident, but didn't take an avoidance action until it was too late.
113	Didn't see other boat/object in time	- The other boat/object was visible for a period of time before this operator took the avoidance action. There is a good possibility that if the avoidance action would have been made at the time that the other boat/object became visible, the collision could have been avoided.
114	Action of other boat or object	- The other boat or object was totally at fault. It made some action that caused the collision to become unavoidable no matter how hard this operator tried to avoid it.

115	Insufficient time	- For some reason, the period of time between the time that the other boat/object first became visible and the time that the collision occurred was so short that the avoidance action was ineffective.
116	Boat malfunction	- Something on the boat malfunctioned causing the avoidance action to be ineffective. Code this block when you aren't certain what actually failed.
117	Engine/Drive train	- The failure that caused the avoidance action to be ineffective was in one or more of the following systems: engine or any attached accessories, gear box, propeller shaft, strut, propeller, rudder, outdrive, or attachment mechanisms.
118	Steering/Controls	- The failure that caused the avoidance action to be ineffective was in one or more of the following systems: steering wheel, steering wheel mechanism, steering cables or pulleys, steering attachment at the rudder end, shift or throttle controls, mechanisms, cables, pulleys or attachment mechanisms.
119	Other	- Something on the boat malfunctioned causing the avoidance action to be ineffective. Code this block when you know what malfunctioned and it was something other than engine/drive train or steering/controls.
120	Other	- The operator took an avoidance action, but that action was nullified by anything other than what is detailed above.
200	This operator did not try to take avoidance action	- Code this block when the probability exists that this operator did not try to take any avoidance action, but you don't know why. You don't know if this operator saw the other boat/object.
201	This operator saw other boat/object	- You know that this operator did not try to take any avoidance action and he did see the other boat/object. You don't know why he did not take avoidance action.
202	This operator thought other boat would avoid collision	- This operator did not try to take any avoidance action even though he saw the other boat because he thought the operator of the other boat would maneuver to avoid the collision.

203	This operator panicked or froze at helm	- This operator did not try to avoid the collision even though he saw the other boat/object because he panicked or froze at the helm.
204	Insufficient time	- The other boat/object appeared so suddenly that there wasn't enough time to take a collision avoidance action.
205	Malicious action	- This operator deliberately tried to place his boat in the collision situation. It may have been because of a dislike for the other person or a desire to see him suffer or it may have been a causeless mischievous impulse.
206	Other	- You know that the other boat/object was seen. You also know that the collision avoidance action was not made for a reason other than those listed above.
211	This operator did not see other boat/object	- You know that this operator did not try to take any avoidance action and he did not see the other boat/object. You don't know why he did not see the other boat/object.
221	Other boat/object probably was recognizable	- You feel certain that the other boat/object could have been seen by most people in the identical situation. Code this block if you don't know why this operator didn't see the other boat/object.
222	This operator not looking	- This operator did not see the other boat/object because he wasn't looking in that direction just prior to the collision.
223	This operator's vision obscured by something on this boat	- The other boat/object was probably recognizable, but this operator didn't see it because of an obstruction on this boat. You aren't sure what was in his line of sight.
224	People	- This operator didn't see the other boat/object because people on this boat were obstructing his view.
225	Objects	- This operator didn't see the other boat/object because an object on this boat obstructed his view.
226	Bow	- This operator didn't see the other boat/object because this boat's bow obstructed his view.
227	Dirty windshield	- This operator didn't see the other boat/object because of spray, salt, dirt, etc., on this boat's windshield.

228	Glare	- This operator didn't see the other boat/object because of glare problems. This can be reflected glare off the water, or off something on this boat. It can also be direct glare from the sun, moon, or any light source.
229	Sails	- This operator didn't see the other boat/object because this boat's sails obstructed his view.
231	Other boat/object probably was not recognizable	- You feel certain that the other boat/object could not have been seen by most people in the identical situation. Code this block if you don't know the reason that it could not have been seen.
232	Underwater object	- This boat hit an underwater object that was not recognizable.
233	Weather/Water conditions	- This operator did not see the other boat/object because the weather conditions or water conditions were so severe. This includes rain, fog, snow, and high waves and assumes that the boat was equipped with weather protection devices normal to similar craft.
234	Improper lighting on other boat/object	- Other boat/object probably was not recognizable by the majority of boaters because it was improperly lighted or not lighted at all.
235	Glare from sources not on this boat	- The other boat/object probably was not recognizable because of glare or lights on the shoreline, on bridges, or causeways or any other source that could effectively mask the navigation lights or the shape of the other boat.
236	Other	- The other boat/object was not recognizable for a reason other than that detailed above.
35	This boat not underway	- The boat is not moving relative to the bottom. The power may be on and, in fact, it may be in gear, but it isn't moving over the bottom.
300	This operator tried to take avoidance action	- You know that the operator saw the other boat/object and that he made some effort to signal or get his boat moving to avoid the collision. Code this block if you don't know what that action was.
301	Other boat/object did not respond to this boat's signals	- Someone on this boat signalled other boat (waved PFDs, used flashlight, etc.), but other boat's operator did not respond at all or not in time to avoid collision.

302	This operator waited too long to respond	- This operator saw other boat, and for some length of time did nothing. When he finally attempted to signal or take an avoidance action, it was too late.
303	This operator didn't see other boat/object in time	- For some reason, the interval between the time that this operator saw the other boat and the collision was too short to signal or take an avoidance action.
304	Other	- Code this block if you know that the operator saw the other boat/object and that he made a specific effort to signal or take an avoidance action other than those detailed above.
321	This boat malfunctioned	- Code this block if you know that this operator tried to get underway, but couldn't. You don't know why he couldn't.
322	Engine problems	- The operator tried to start the engine, but couldn't.
323	Anchor problems	- Someone on board this boat attempted to weigh anchor, but couldn't for some reason such as: anchor caught in some object, anchor line tangled, current too strong so anchor line couldn't be pulled in, or engine was started and boat was underway before anchor line was pulled in. Result, line tangled in propeller.
324	Other	- Code this block when a specific boat malfunction occurred other than the two listed above.
331	Other	- Code this block when the operator tried to take a specific avoidance action or made a specific signal that won't fit in any other block.
400	This operator did not try to take an avoidance action	- You know that the operator saw the other boat/object, but he did not make any effort to signal or get his boat moving to avoid the collision. Code this block if you don't know any more details.
410	Insufficient time	- He didn't take any avoidance action because he didn't have time.
421	This operator saw other boat/object	- Code this block if you know that the operator saw the other boat/object, but you don't know anything else.

422	This operator thought other boat would avoid collision	- This operator saw the other boat coming, but didn't signal or attempt to take an avoidance action because he thought the other boat would eventually change course and wouldn't hit him.
423	This operator panicked	- This operator saw the other boat coming at him and obviously panicked or froze.
424	Other	- This operator saw the other boat coming at him and did not try to take any avoidance action for a specific reason other than those mentioned above.
431	This operator did not see other boat/object	- You know that this operator did not try to take an avoidance action because he did not see the other boat/object. Code this block only if you don't know whether the other boat/object was recognizable.
441	Other boat/object probably was recognizable	- You feel certain that the other boat/object could have been seen by most people in the identical situation. Code this block if you don't know why this operator didn't see the other boat/object.
442	This operator not looking	- This operator did not see the other boat/object because he wasn't looking in that direction just prior to the collision.
443	This operator's vision obscured by something on this boat	- The other boat/object was probably recognizable, but this operator didn't see it because of an obstruction on this boat. You aren't sure what was in his line of sight.
444	People	- This operator didn't see the other boat/object because people on this boat were obstructing his view.
445	Objects	- This operator didn't see the other boat/object because an object on this boat obstructed his view.
446	Bow	- This operator didn't see the other boat/object because this boat's bow obstructed his view.
447	Dirty windshield	- This operator didn't see the other boat/object because of spray, salt, dirt, etc., on this boat's windshield.

448	Glare	- This operator didn't see the other boat/object because of glare problems. This can be reflected glare off the water, or off something on this boat. It can also be direct glare from the sun, moon, or any light source.
449	Sails	- This operator didn't see the other boat/object because this boat's sails obstructed his view.
451	Other boat/object probably was not recognizable	- You feel certain that the other boat/object could not have been seen by most people in the identical situation. Code this block if you don't know the reason that it could not have been seen.
453	Weather/Water conditions	- This operator did not see the other boat/object because the weather conditions or water conditions were so severe. This includes rain, fog, snow, and high waves and assumes that the boat was equipped with weather protection devices normal to similar craft.
454	Improper lighting on other boat/object	- Other boat/object probably was not recognizable by the majority of boaters because it was improperly lighted or not lighted at all.
455	Glare from sources not on this boat	- The other boat/object probably was not recognizable because of glare or lights on the shoreline, on bridges, or causeways or any other source that could effectively mask the navigation lights or the shape of the other boat.
456	Other	- The other boat/object was not recognizable for a reason other than that detailed above.
461	This boat malfunctioned	- Code this block if you know that the operator didn't try to signal and didn't try to take an avoidance action because he knew he had a malfunction. You aren't sure what type of malfunction occurred.
462	Engine problems	- The operator knew the engine wouldn't start or the boat wouldn't move due to engine or drive train problems.
463	Anchor problems	- The operator didn't even try to weigh anchor because he knew he couldn't get it up.
464	Other	- Something on the boat malfunctioned causing it to be dead in the water. Code this block when you know that the operator didn't try to signal, didn't try to take an avoidance action, and you know what malfunctioned and it wasn't the engine, drive train, or anchoring problems.
500	No operator on this boat	- The boat is anchored, moored, or docked with nobody aboard.

95%

APPENDIX B
STATISTICAL TESTS

Most of the statistical analysis of the collision sample involved the use of one of two statistical tests on 2 x 2 contingency tables. These were the Fisher exact test and the Chi-Square test.

The Chi-Square test involves using a statistic which is approximated by the χ^2 distribution for sufficiently large sample sizes. In general, a sample size is considered sufficiently large if every cell of a 2 x 2 table contains at least five data points. When this is not the case, a Fisher exact test should be used.

The calculations of the Chi-Square statistics made use of a special formula appropriate for 2 x 2 tables and equivalent to the more usual formula. In particular, given the contingency table:

a	b	a + b
c	d	c + d
a + c	b + d	n

where

$$n = a + b + c + d,$$

$$\chi^2 = \frac{n\left(\left| ad - bc \right| - \frac{n}{2}\right)^2}{(a+b)(c+d)(a+c)(b+d)}.$$

This statistic is corrected for continuity, the term $-\frac{n}{2}$ being Yate's correction factor.

The Fisher exact test computes the probability of getting a result at least as extreme as the one obtained, given that the marginal totals remain fixed. The significance level of the test is the sum of probabilities obtained from the original contigency table and ones with more extreme cell frequencies. Each term in the sum is calculated in the same manner. The formula for the first term (the one corresponding to the original table) is:

$$p = \frac{(a+b)!\ (c+d)!\ (a+c)!\ (b+d)!}{n!\ a!\ b!\ c!\ d!}.$$

While the Chi-Square test is a two tail test, the Fisher exact test is a one tail test. The usual procedure, and the one adopted here, for converting it to a two tail test is to multiply the probability obtained by two. Unless otherwise specified, all tests were two tail tests, testing the hypothesis of independence against the alternative hypothesis of non-independence.

Although the Chi-Square test is well known, some individuals may be unfamiliar with the Fisher exact test. We, therefore, provide an example of its application. In this example, taken from Section 4.0, we shall also illustrate how frequencies were obtained for the "second tests" in which cause comparisons were made only among boats underway for which there could be no ambiguity as to cause.

Example: Testing Cause 222: Daytime vs. Nighttime

The "second" test of Cause 222 has the initial contingency table:

15	60	75
1	40	41
16	100	116

The frequencies in this table were obtained as follows: In Figure 4-3 we find that fifteen collision-involved boats operating during the day were coded with Cause 222 and only one night-operating boat was coded with this cause. To determine the total number of daytime-operating boats underway which could not be coded with Cause 222, we look at Figure 4-4 and find that ninety-six boats were underway during the daylight hours. Referring again to Figure 4-3, we see that of the ninety-six boats, thirteen were coded Cause 15, five were coded Cause 200 and three were coded Cause 221. It is uncertain as to how many of these boats would have been coded with Cause 222 if sufficient information had been present. Thus, we do not include them in our calculations, leaving 96 - 13 - 5 - 3 = 75 boats. Of these boats, fifteen were coded Cause 222, so 75 - 15 = 60 boats could not have been so coded. The frequency of forty nighttime-operating boats which could not have been coded with Cause 222 is obtained similarly.

The Fisher exact test probability is computed as follows:

From the table

15	60	75
1	40	41
16	100	116

we obtain the probability

$$p_1 = \frac{75!\ 41!\ 16!\ 100!}{116!\ 15!\ 60!\ 1!\ 40!} = 0.00538 .$$

We then "adjust" the table to obtain a more extreme result, retaining the same marginal totals. The new table is:

16	59	75
0	41	41
16	100	116

The probability associated with this table is:

$$p_2 = \frac{75!\ 41!\ 16!\ 100!}{116!\ 16!\ 59!\ 0!\ 41!} = \frac{1 \cdot 60}{16 \cdot 41} p_1 = 0.00049 .$$

As one cell frequency is 0, no more extreme result is possible. We thus have $p_1 + p_2 = 0.00587$ as the probability of obtaining a result at least as extreme in the same direction as that in the original table. This is a one tail result. To obtain a two tail probability we follow the usual practice and double the one tail probability, obtaining $p = 0.01174 = 1.2\%$. Further descriptions of the statistical tests may be found in Reference 26.

The odds ratio contingency coefficient o was used in Section 3.0. This coefficient compares the odds for a factor B being present given that a factor A is present, to the odds for B being present given that A is absent.

Thus

$$o = \frac{\text{odds }(B|A)}{\text{odds }(B|\bar{A})} = \frac{\dfrac{p\,(B|A)}{1 - p\,(B|A)}}{\dfrac{p\,(B|\bar{A})}{1 - p\,(B|\bar{A})}}$$

o may be readily calculated from a contingency table. Using the same notation as before, $o = \frac{ad}{bc}$, provided this quotient exists. Once it has been determined that statistical significance exists for acceptance of the non-independence hypothesis, the odds ratio furnishes a rough guide to the degree of association of the factors. A large value of o indicates a strong positive (direct) relationship. A value of o close to zero indicates a strong negative (inverse) relationship. A value of o close to one indicates a weak relationship. Note, however, that values of ∞ or 0 do not indicate perfect relationships. For further information, consult Reference 19.

APPENDIX C

RELATING A FACTOR TO THE CAUSE(S) OF A COLLISION

Wyle researchers classified collision causes by a number of schemes. In each case engineering judgment was used in order to determine whether a cause was probably, possibly, or unlikely to be related to a factor, such as stressors, boat malfunctions, etc. A cause was classified as "probably" related to factor if it was judged that there was a 60% to 100% likelihood of there being a definite relationship. The judgment that there was a 30% to 60% likelihood of a definite relationship resulted in a cause being classified as "possibly" related to a factor. A judgment that the likelihood of a definite relationship was less than 30% resulted in the cause being classified as "unlikely" to be related to the factor.

In the case of two-boat collisions, two causes were coded for each collision. If one wishes to relate a factor to the causes of a two-boat collision, one must then make a decision as to how the relationship of the factor to each of the two boats' causes result in a relationship of the factor to the entire collision. That is, do two "possibly's" make a "possibly" or a "probably," etc. The decision was made to relate a factor to a collision based on the likelihood that the factor was related to the cause for either or both boats. The following formula therefore applied, where P represents probability or likelihood.

P (factor is related to collision)

= P (factor is related to Boat 1 cause or factor is related to Boat 2 cause)

= 1 - P (factor is related to neither cause)

= 1 - P (factor is not related to Boat 1 cause) P (factor is not related to Boat 2 cause)

(For this rough classification procedure, the assumption is made that the relationships of a factor to two causes in a two boat collision are independent of each other.)

Applying the formula yields the following table.

Relationship of A Factor To A Two-Boat Collision

			Relationship To Boat 1 Cause		
			Unlikely $P \approx 15\%$	Possibly $P \approx 45\%$	Probably $P \approx 80\%$
Relationship To Boat 2 Cause	Unlikely	$P \approx 15\%$	$P \approx 28\%$ (Unlikely)	$P \approx 53\%$ (Possibly)	$P \approx 83\%$ (Probably)
	Possibly	$P \approx 45\%$	$P \approx 53\%$ (Possibly)	$P \approx 70\%$ (Probably)	$P \approx 89\%$ (Probably)
	Probably	$P \approx 80\%$	$P \approx 83\%$ (Probably)	$P \approx 89\%$ (Probably)	$P \approx 96\%$ (Probably)

The relationships on this table are the ones used in the text to relate a factor to the causes of a two boat collision.

APPENDIX D
SIGNAL DETECTION THEORY

Although it is true, as stated in the body of the report, that the measure d' can be considered merely as a means of transforming two types of error scores (the probability of missing a signal when one is presented and the probability of responding to a non-signal) into a single score (d'), the measure has theoretical and statistical importance. The purpose of this appendix is to provide the interested reader with insight into the derivation and significance of d'.

A major concern of psychology for over a century has been the identification of sensory thresholds. The theory of signal detection (first proposed in 1954) has challenged the concept of sensory thresholds, proposing instead response thresholds. The theory can trace its origins to statistical decision theory and electrical engineering (out of concern for the design of sensing devices). The major contribution of psychology, causing the development of the theory, was the identification of the distinction between the sensor and the decision maker in the human observer. These two aspects are confounded in sensing machines and human performance. The theory of signal detection (hereafter abbreviated TSD) makes possible the precise distinction between these two functions of the observer of signals who must: 1) sense the signal, and 2) decide it was indeed a signal that he sensed. The theory can be used as an application of statistical decision theory to single trials in psychophysical experiments. The subject in such an experiment must be aware that there are two possible states of the world: 1) one state when a signal is present, and 2) another state when there is a non-signal. Once the subject is aware of the nature of these two states, information is presented to him on a trial by trial basis. On each trial, he must decide whether a signal was present or not. VAST is an experiment of this type, where light patterns are displayed trial by trial and the subject must decide whether or not to respond.

On any one trial, the subject may respond, "Yes, I detected a signal," or, "No, I didn't," and a signal may or may not be present. Thus, each trial can be represented in the matrix shown in Figure D-1. When there was a signal and the subject responds correctly, a "hit" is scored. In VAST, the subject depressed the response button on the throttle to respond "Signal," and did nothing to respond "No Signal."

		Response	
		Signal	No Signal
Stimulus	Signal	"Hit"	"Miss"
	No Signal	"False Alarm"	"Correct Rejection"

FIGURE D-1. STIMULUS/RESPONSE MATRIX

Similarly, a payoff matrix can be constructed to show the rewards or punishments for various results. The entries in the payoff matrix can be monetary rewards/punishments, or whatever is used in the particular experiment or situation. If the signal were ICBMs approaching the USA and the radar operator were to "miss" the signal, the payoff could be complete annihilation, without retaliation. In the case of VAST-2 and VAST-3, the payoffs were as shown in Figure D-2. In VAST-1, there were no payoffs (no feedback to the subject).

		Response	
		Signal	No Signal
Stimulus	Signal	V_{ss} = Happy Face	V_{ns} = Nothing
	No Signal	V_{sn} = Buzzer	V_{nn} = Nothing

FIGURE D-2. PAYOFF MATRIX

In the experiment described above, the observer has an observation (let us call it z) for which he can compute (estimate) the probability of the observation given that no signal was presented ($p(z/n)$) and the probability of the observation given a signal was presented ($p(z/s)$). Using these two quantities, the likelihood ratio ($l(z)$) can be computed. This corresponds to the probability of the observation given a signal divided by the probability of the observation given no signal was presented, as shown in Equation D-1.

$$l(z) = \frac{p(z/s)}{p(z/n)} \tag{D-1}$$

If the subject knows, or can estimate, the prior odds of a signal versus a non-signal $\left(= \frac{p(s)}{p(n)}\right)$, he can compute the odds in favor of a signal as opposed to a non-signal given his observation by Bayes' Theorem (Equation D-2).

$$\text{Posterior Odds} = \frac{p(s/z)}{p(n/z)} = \frac{p(z/s)\ p(s)}{p(z/n)\ p(n)} = \text{Likelihood Ratio} \times \text{Prior Odds} \tag{D-2}$$

If the observer chose to respond according to his expected payoff, then he would respond "Signal" if, and only if, the payoff for a "hit" times the probability of a "hit" ($V_{ss} \cdot p(s/z)$) minus the probability of a false alarm times the payoff for a false alarm ($V_{sn} \cdot p(n/z)$) is greater than the expected value of a "No Signal" response ($= V_{nn} \cdot p(n/z) - V_{ns} \cdot p(s/z)$). This response rule is equivalent to responding "Signal" if, and only if, Equation D-3 is true.

$$\frac{p(s/z)}{p(n/z)} \geq \frac{V_{nn} + V_{sn}}{V_{ss} + V_{ns}} \tag{D-3}$$

Substituting Equation D-2 for the left-hand side of Equation D-3 yields,

$$\frac{p(z/s)}{p(z/n)} \geq \frac{p(n)}{p(s)} \cdot \frac{V_{nn} + V_{sn}}{V_{ss} + V_{ns}} \tag{D-4}$$

If we call the expression on the right β, using Equation Equation D-1 yields,

$$l(z) \geq \beta \tag{D-5}$$

Thus, β is that number which accounts for the prior odds and payoffs so as to maximize the expected payoff. The subject can maximize his expected payoff if he responds "Signal" when $l(z)$ is at least as great as β, and "No Signal" otherwise. Thus, β represents the subjects optimal decision criterion based upon the likelihood ratio and the payoff matrix.

The performance of any sensing device (human or otherwise) can be described in TSD by a receiver operating characteristic curve, or ROC curve. For the value β described previously there will be a corresponding observation z_c (c for "criterion") such that all observations exceeding z_c will lead to Equation D-5 being true. Thus, whenever the subject's observation

exceeds z_c, he should respond "Signal" to maximize his expected payoff. The ROC curve plots the hit rate (the probability the subject responds "Signal" when a signal was present) versus the false alarm rate (the probability the subject responds "Signal" when a non-signal was present) as shown in Figure D-3. Each point on the curve corresponds to one value of β. Various points are plotted as β is manipulated using changes in the payoff matrix or the prior odds.

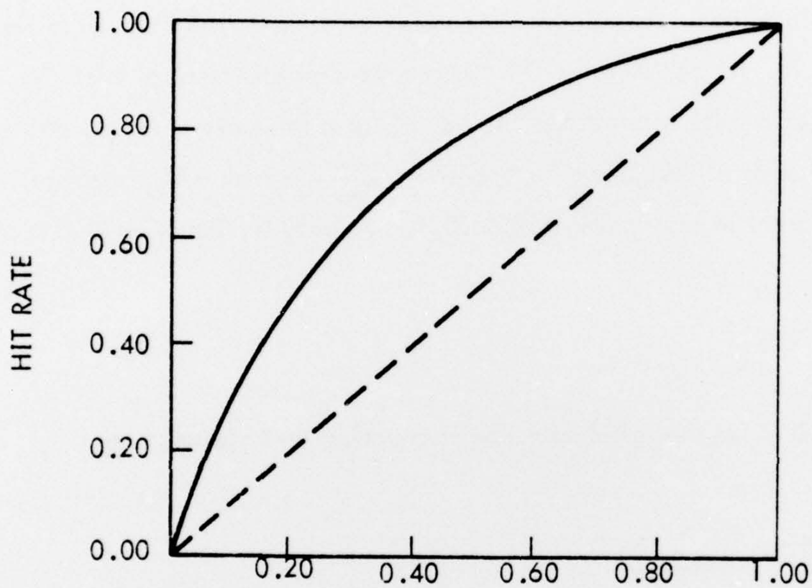

FIGURE D-3. ROC CURVE

For example, if the subject were always punished for responding "Signal," he would never respond and his false alarm and hit rates would both be zero. On the other hand, if he were always rewarded for responding "Signal," he would always respond "Signal," and his hit rate and false alarm rate would both be one. In the former case, β and z_c would be set as high by the subject as to never be exceeded, while in the latter case, they would be so low as to always be exceeded by an observation.

If the signal were somehow to be intensified or increased, so that it was easier to distinguish from a non-signal, then the subject's error rates would drop while his hit rate increased (assuming the same β). He would have moved to a higher ROC curve as shown in Figure D-4.

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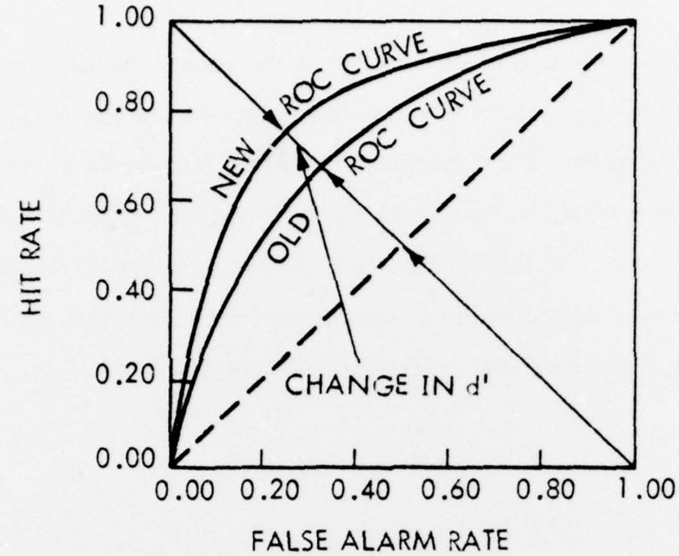

FIGURE D-4. MULTIPLE ROC CURVES

The difference between the two curves can be expressed in terms of the differences in d', which relates to the distance from the major diagonal in the figure to the ROC curve, along the minor diagonal. Since the greater d' is, the higher the possible hit rate under a fixed false alarm rate, d' is a measure of the subject's accuracy, or sensitivity to the difference between a signal and a non-signal.

How can d' be determined? Figure D-5 shows hypothetical distributions of the probability of an observation given no signal was presented (p(z/n)) and the probability given a signal was presented (p(z/s)), and a criterion value of z_c (any z observed which is greater than z_c results in the response "Signal"). The shaded area under the p(z/s) distribution shows the proportion of hits. The shaded area under the p(z/n) distribution shows the proportion of false alarms.

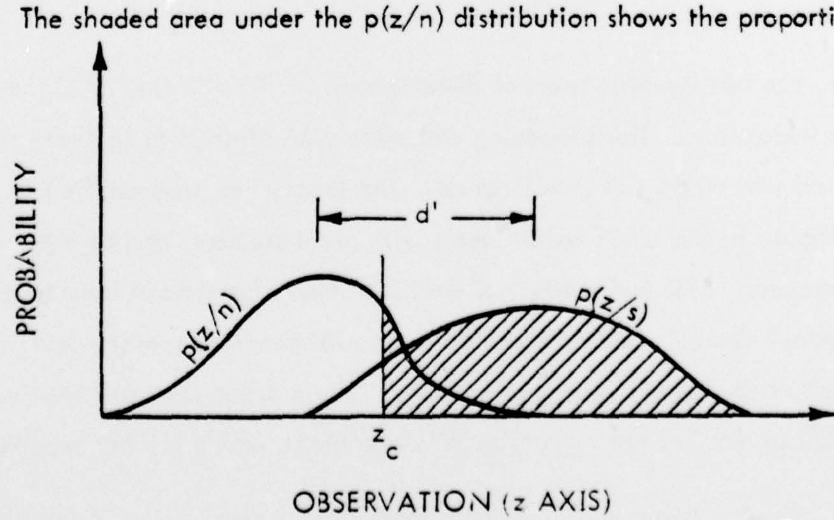

FIGURE D-5. PROBABILITY DISTRIBUTIONS

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Similarly, the white area under the $p(z/n)$ distribution is the proportion of correct rejections, while the white area under the $p(z/s)$ distribution is the proportion of missed signals. The quantity d' represents the separation of the means of these two distributions, as shown in the figure. The distributions are assumed to be normal and of constant variance. β is equal to the ratio of the ordinate of the $p(z/s)$ distribution at z_c to the ordinate of the $p(z/n)$ distribution at z_c. Under the assumptions of normality and constant variance, and letting Z_n and Z_s be the standard (normalized) score of z_c under the non-signal and signal distributions, respectively, then,

$$d' = Z_n - Z_s \qquad \text{(D-6)}$$

Note that the major diagonal of an ROC curve corresponds to $d' = 0$. This happens when the two distributions in Figure D-5 have the same mean and the subject is essentially guessing. In those circumstances z_c is equal to the shared mean (assuming balanced payoffs) and a response of "Signal" is just as likely to be in error as it is to be correct. The greater d' is, the easier it is for the subject to discriminate between a signal and a non-signal, and the fewer the number of errors he makes of both types (false alarms and missed signals), assuming a fixed β. His ROC curve is closer to the point (1,0). If d' is small, then the subject has difficulty distinguishing between a signal and a non-signal, his error rates are high, and his ROC curve is close to the major diagonal in Figure D-4. Boosting the signal intensity adds a constant to the $p(z/s)$ curve in Figure D-5 and results in an increase in d'. Note that the variance is assumed to be constant; i.e., it is assumed that there is no inherent variation in boosting the signal.

To summarize the twenty-plus years of development of "The Theory of Signal Detection" in a few pages is impossible. The preceding was merely an attempt to indicate that the measure d' has theoretical and statistical significance. The theory has been applied to numerous circumstances analogous to the VAST experiments with great success, and to other circumstances with equivalent success. TSD and statistical decision theory have been used to study the existence of ESP (a "weak" signal), and to evaluate the performance of sensory devices in the space program, such as the recent Mars explorations. There are many more implications and ramifications of TSD in the field of sensory psychology alone which are not reported here. It is

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hoped that the reader has gained an appreciation for TSD and the measure d'. It appears from past research that for a given observer and signal to non-signal ratio (i.e., constant definition of signal and non-signal), d' is reasonably constant over variations in β (prior odds and payoff matrices) and in experimental procedures (form of responding: "Signal" versus "No Signal," confidence ratings, matching techniques, etc.). It is the accomplishment of TSD in providing predictability and integration over a range of experimental conditions and procedures that has prompted a great deal of interest in the theory.

In the case of the application of TSD to VAST-3 data in the form of computing d' scores, it should be noted that the payoff matrix for the subjects was not monetary or reward oriented. The subjects in VAST merely became aware of the appropriateness of their responses through feedback. Thus, the values of the entries in the payoff matrix were the corresponding subjective desire, competitive drive, or motivation of the subjects to perform well. The subjects in VAST-1 were USCG personnel who expressed competitive sensitivities since they each represented different USCG units. In VAST-2 and VAST-3 the subjects appeared to be self-motivated, attempting to perform well as a matter of pride in accomplishment as well as in response to competitive drives.

GLOSSARY

This glossary of psychological and statistical terms is provided for those readers who may not be familiar with their technical meanings. The glossary has taken the form of conceptual discussions and examples rather than terse dictionary definitions.

F Statistic/Analysis of Variance

The usual hypothesis under test in an analysis of variance (using the F statistic) is that the mean scores under all treatments (score = whatever you are measuring, treatment = set of levels of variables, the conditions corresponding to a data cell or set of data cells) are equal. Call this hypothesis H_0. The alternative is called H_1: not H_0; i.e., H_1: all population mean scores are not equal. Another way to express these hypotheses is as follows,

H_0: all effects of variables in the experiment are zero

H_1: one or more effects are non-zero.

The F statistic is used to test for the rejection of one of the two hypotheses. In order to compute the F statistic, one must have data (scores) which are normally distributed in the population being investigated. In cases where the data are not normally distributed (such as the response times in VAST-2 and VAST-3), then a transformation can sometimes be found so that the transformed data are more normally distributed. Then the analysis of variance can be performed on the transformed data. This was done in VAST-2 and VAST-3.

In the computations, the scores are subtracted from the mean within a group of scores and the differences are squared and summed. This is done for each possible combination of variables within an experiment. The results are typically listed in an analysis of variance summary table under "sum of squares." An example can be found in Table 2-11. The total sum of squares is found by summing the squared differences between the individual scores and the overall mean. The degrees of freedom are equal to the number of categories minus one for an individual variable. For an interaction of variables, the degrees of freedom is equal to the product of the degrees of freedom for the variables in the interaction. This concept originates from the fact that if one knows the overall mean score for a variable, the means for the individual

categories are "free" to vary except that once all but one is determined, it can be calculated from the overall mean and the other category means. When data are estimated from existing data, a degree of freedom is lost for each datum that is estimated. This occurred in VAST-3 and is shown in Table 2-11.

The F statistic is computed for any factor or set of factors by dividing the mean square (mean square = sum of squares divided by degrees of freedom) for the factor or factors by the mean square for the appropriate error term. The appropriate error term is chosen by procedures which are too lengthly to discuss for every case here. Basically, the error term is chosen to measure variability within each category of a variable (while the mean square for the factor or factors of interest measures variability between, or, due to, that factor or factors). In Table 2-11 the error terms corresponded to the factor or factors crossed with the subjects variable, since the subjects were the only factor varying within all levels of each factor. In that example, the factor of subjects had its own sum of squares, representing the residual variance attributable to individual differences between subjects after all other sources of variation had been accounted for. The label "source" is at the top of the table to indicate the source of variation for the computations to the right in the table. To study this table further, the entries to the right of alcohol represent the variation in the data attributable to differences between alcohol levels, while the entries to the right of A x S represent the variation attributable to individual differences within those alcohol levels. F is computed as the ratio between the sums of squares divided by degrees of freedom. Thus,

$$F = \frac{0.115}{2} \div \frac{0.021}{4} = 10.952$$

Under the assumptions described above (normality of the population distributions), when the null hypothesis (H_0) is true, then this ratio is distributed as the random variable F. Thus, one can consult a table of the random variable F for two and four degrees of freedom to find the value corresponding to a particular significance level (see this term in the glossary) and compare this to the obtained value. For α (significance level) = 0.025 the corresponding F value is 10.65. Our computed value based upon the data in Table 2-11 is 10.952. Thus, the probability of obtaining these data under H_0 is less than 0.025. H_0 is rejected and H_1 is accepted; i.e., there is a statistically significant difference in the scores due to alcohol.

Feedback Cues

In order for a person's behavior to be controlled or altered, it is necessary that the consequences of his responses be communicated to him (specifically to the mechanisms that initiated his behavior). This communication is the process of feedback. The communication can take the form of presenting cues (sensory inputs in the case of VAST) to the person which portray the result of the person's action. In VAST, the negative feedback cues were the buzzer for an incorrect response and the horn for being off course. The happy face was a positive feedback cue. Feedback has the property of providing motivation for behavior and hastening learning.

Individual Differences

People vary on many parameters. Among other things, they vary on their susceptibility to stressors and their abilities to perform on tasks such as VAST. These individual differences contribute to the variability in data on experiments such as the VAST experiment and are responsible for techniques developed for such experiments to compare data and account for that subject-induced variability. One of the faults of all-encompassing standards that are applied to people is that they often fail to account for individual differences. Thus, new guidelines or programs designed to affect people (whether they are oriented toward stressors, or cockpits, or something else) should allow for individual differences in abilities, reactions, physical dimensions, etc. - and at least specify the range or types of people that the guideline or program is supposed to help or apply to.

Information Processing

In psychology the term "information processing" refers to the perceptual and cognitive functioning of people. Viewed as an input-output system, the human accepts data or information through his senses, processes it, and emits responses through his skeletal, muscular, and/or vocal systems. Theories and fields of psychology have been developed to investigate each aspect of the human information processing system. A great amount of research has been performed to study the processing functions from the sensory input to the output of electrical potentials to the muscular and vocal systems. The dimensions of these studies have defined the "information processing capabilities" of man. There are more technical definitions of

these terms in the psychological literature (technically, information is defined as that which opposes entropy), and the interested reader is referred to Human Information Processing (by Lindsay and Norman, New York: Academic Press, 1972).

Interaction

To say that two or more variables interact significantly with each other means that the effect of one variable does not remain the same across different levels of the other, or others. An example is found in Table 2-5, where the interaction between alcohol and fatigue in VAST-2 is illustrated. Note that within the "rested" category, alcohol led to an average increase in response time of over 300 milliseconds, while within the "fatigued" category, alcohol led to an average decrease in response time of slightly over 200 milliseconds. The effect of alcohol varied across different levels of fatigue, indicating the interaction of the two variables. If alcohol had led to an average increase in response time of 1000 milliseconds under fatigue, then that also would have indicated a significant interaction because of the difference under no fatigue being less than 400 milliseconds. In this hypothetical case, the interaction would have been of a different nature than the one illustrated in Table 2-5. Finally, if the effect of alcohol under fatigue had been an average increase in response time of approximately 350 milliseconds (as it was under "no fatigue"), then there would have been no evidence of an interaction between fatigue and alcohol, i.e., the effects would have been additive and the interaction would have been zero. To the extent that the effects of variables in combination do not reflect simply adding their individual effects, there is interaction. F tests and other statistical procedures are available to test for the significance of interactions.

Reaction Time/Response Time

The two terms "reaction time" and "response time" are often confused, or thought of as being equivalent. As long as it is understood that they are being treated as equivalent terms, no problem exists. However, within the context of this report (and according to some psychologists), there is a distinction. The reaction time of a subject is the time from the onset of a stimulus to the completion of his internal processing of that event prior to the execution of a response. The response time would include the reaction time plus the time required to execute a response. In practice, response times are observable and are usually what are measured. Reaction times

can be measured in some cases using electrodes planted in the central nervous system and making some assumptions about neural functioning. However, such techniques and measurements are beyond the scope of this project. The term "one psychological reaction time" is often used to refer to the fastest known signal-response human processing time (pushing a button with one finger in response to a mild shock felt through that button) of about 200 msec. This concept was used in the 19[illegible] Olympics to judge false starts. Anyone who started a race sooner than 200 msec from the signal to start was charged with a false start.

Signal/No Signal/Proportion of Missed Signals/Trials

Within any stimulus-response experiment, the subject must be made aware of what is to be responded to. This is known as the "signal." If the subject is to respond only when no lights are on on the VAST apparatus, for example, then the "signal" would be "no lights." In the experimentation that was done in VAST-1, VAST-2, and VAST-3, the signal was any light which stayed on for more more than one second. Sometimes lights were on for periods equal to or less than one second and the pattern of these appeared to be one (or more) "moving" light(s). These light patterns (any without a "non-moving" light) were classified as non-signals. The proportion of missed signals was calculated by dividing the number of signals that were not responded to by the total number of signals in the VAST test run. Each presentation of a light pattern or patterns (contiguous in time) constituted a trial. The hit rate equals the number of signals responded to divided by the total number of signals. The false alarm rate equals the number of responses to non-signals divided by the total number of non-signals, while the proportion of correct rejections equals the number of non-signals that were not responded to divided by the total number of non-signals in the VAST test run.

Significance/Marginal Significance

When statistical results are reported, the level of significance is usually indicated. As indicated above with the discussion of the F statistic, hypotheses are generally accepted or rejected with some probability of error. In the example discussed there, H_0 was rejected at the 0.025 level of significance (usually reported "significant at $p < 0.025$"). This meant that the probability of obtaining those data given H_0 was true was less than 0.025. However, the probability

that one has falsely rejected the null hypothesis (falsely rejected H_0) is equal to that small probability that is less than 0.025. This is known as the "significance" of the result or "the probability of Type I error." By convention, a significance level of 0.05 has been chosen by many professionals in the behavioral sciences as the accepted probability of Type I error. A result with a significance level greater than 0.05 is labelled "not significant" by the same convention. Type II error refers to the probability of falsely rejecting H_1 when H_0 is accepted. This is known as the "power" of the statistical test. "Marginal significane" is a term that is used to define results that are nearly significant (but not quite) when the investigator is willing to tolerate a slightly higher probability of Type I error than 0.05. This is often the case when the probability of observing a significant result is small due to large individual differences or some other reason (this is equivalent to having a high probability of Type II error). Significance levels are often expressed using the Greek letter α or the English letter **p**.

Stress/Stressors

A discussion of these terms can be found in Section 2.2 Problem Definition. In terms of the VAST experiments, stress can be defined by the combination of levels and durations of exposure to manipulated environmental factors and alcohol experienced by the subjects. Individual stressors were the individual factors that were manipulated (glare - with sunglasses, alcohol - by ingesting measured quantities, etc.). Other stressors (heat, humidity, etc.) were present and neither controlled (other than by using counterbalancing in the design) nor analyzed to any significant degree (some temperature and wind data were collected and noted).

t Statistic

One of the uses of the t statistic and t distribution is to make inferences about the differences between means. Under the assumption that the sampling distributions of the two sets of data used to generate the means are approximately normal one can investigate the significance of the difference between the observed mean scores using the t statistic. Using the logic outlined above for the F statistic, one tests for the rejection of the hypothesis that the means are not different. Let the hypotheses under test be defined as,

H_0 : the difference between the mean scores is zero

H_1 : the difference between the mean scores is not zero.

The difference between the means is then computed and divided by an estimate of the standard error of the difference (determined from the sum of squared deviations from the mean for each set of data and the number of scores in each set of data). The degrees of freedom in this case would be equal to the total number of data points used minus 2 (because two means were computed in the t statistic computations). In the example in Table 2-11, the calculations were made as shown below, using transformed response times,

M_c = Mean-Controls = 3.269

M_A = Mean-Alcohol = 3.331

S_c^2 = Sample Variance-Controls = 0.053

S_A^2 = 0.078

N_c = No. of data points-Controls = 56

N_A = 60

$$\text{estimated } \sigma_{\text{difference}} = \sqrt{\frac{S_c^2}{N_c - 1} + \frac{S_A^2}{N_A - 1}}$$

$$t = \frac{M_c - M_A}{\text{est. } \sigma_{\text{diff.}}} = \frac{0.062}{0.0168} = +3.69.$$

Under the assumption that the two sampling distributions are normally distributed, the number calculated above is distributed as the random variable t.

With $N_c + N_A - 2 = 114$ degrees of freedom, $t = +3.69$, $p < 0.001 \Rightarrow$ the difference between the means is statistically significant, and H_0 is rejected.

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